ECONOMIC OPTIMISATION OF DOMESTIC SOLAR HOT WATER FOR THE COMMERCIAL MARKET USING CONSOL EVACUATOR TUBE PANELS IN CHRISTCHURCH, NEW ZEALAND

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Acknowledgments

So two years and almost 10,000 earthquakes later I have plenty more grey hairs, an expanding waist and many other delightful things to add to my life. However, looking back over the long two years completing this thesis part-time while working full-time there are a lot of people to acknowledge and thank along the way. The past two years has not been easy on anyone.

Firstly my parents, without their night of joy I would not be here, lets not forget them!!! However, being in Wellington and not really having any idea of what I am doing (or why on earth I am doing it) they always provide unconditional love and encouragement to anything in my life. A mother's love can be second to none and a father's advice is always the best advice you can receive.

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Also I would like to thank the people that helped fund the research including Matt from Consol New Zealand Limited, and Sam and Andre from Set Point Solutions. The help, encouragement and generosity from the industry have been very much appreciated. I hope the outcomes are useful to all.

Finally like the dream when I was winning an Oscar, we must not forget God – we can only live in awe of you! Everyone around the world is studying to understand only a fraction of what brilliance you have produced for us here on Earth.

Abstract

Domestic solar hot water is becoming a more common technology used specifically with the residential market of New Zealand. Recently domestic solar hot water systems have been economically identified as an option in commercial applications. Commercial building owners in the corporate world generally base decisions on economic reasons, therefore this research investigates the need to economically optimise the size of domestic solar hot water systems for eight separate commercial applications within Christchurch. All modelling has been completed using Consol's heat pipe evacuator tube panels orientated North at an angle of 45 degrees.

The TRNSYS simulation program is utilised to model the domestic solar hot water system in the eight commercial applications. Each commercial application has a unique domestic hot water load profile. The heat pipe evacuated tube is locally available from Consol New Zealand Limited. A common proportional relationship was utilised to define the relationship between the size of the storage tank and area of solar panels, which enables a range of domestic solar hot water system sizes to be used in the simulations.

A proportional relationship is identified to economically optimise the size of commercial domestic solar hot water systems in Christchurch. This

proportional relationship enables engineers and designers of commercial domestic hot water systems to confidently implement domestic solar hot water system designs. This provides an economically optimal solution in regards to the size of the solar component that should be installed during the rebuild of Christchurch.

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Nomenclature

A	Total collector array aperture or gross area (consistent with $F_R(\tau\alpha)$. F_RU_L, $F_RU_{L/T}$ and G_{test}).
$\mathbf{A_c}$	Cross sectional area
$\mathbf{A_{c,i}}$	Cross sectional area of a node
$\mathbf{A_I}$	Anisotropy index
$\mathbf{A_{s,i}}$	Surface area of a node
$\mathbf{a_0}$	Interceptor of collector efficiency versus $\Delta T/I_T$.($F_R(\tau\alpha)_n$, $F_{av}(\tau\alpha)_n$, or $F_O(\tau\alpha)_n$)
$\mathbf{a_1}$	Negative of the first-order coefficient of the collector efficiency versus $\Delta T/I_T$
$\mathbf{a_2}$	Negative of the second-order coefficient of the collector efficiency versus $\Delta T/I_T$
$\mathbf{b_0}$	Negative of the first order coefficient of $(\tau\alpha)_b/(\tau\alpha)_n$ vs. $(1/\cos\theta-1)$
$\mathbf{b_1}$	Negative of the second order coefficient of $(\tau\alpha)_b/(\tau\alpha)_n$ vs. $(1/\cos\theta-1)$
$\mathbf{C_p}$	Specific heat of fluid
$\mathbf{d_o}$	Diameter of the coil
$\mathbf{F_R}$	Overall collector heat removal efficiency factor
$\mathbf{F_RU_L}$	Negative of the first-order coefficient of collector efficiency versus $(T_i-T_a)/I_T$
$\mathbf{F_RU_L'}$	Combined first and second-order coefficients of collector efficiency versus $(T_i-T_a)/I_T$
$\mathbf{F_RU_{\frac{L}{T}}}$	Negative of the second-order coefficient of collector efficiency versus $(T_i-T_a)/I_T$
$\mathbf{F_R(\tau\alpha)_n}$	Intercept of collector efficiency versus $(T_i-T_a)/I_T$
f	Modulating factor for Reindl tilted surface model
$\mathbf{h_o}$	Outside convection coefficient for internal heat exchanger
I	Total horizontal radiation per unit area
$\mathbf{I_{bT}}$	Incident beam radiation per unit area
$\mathbf{I_d}$	Horizontal diffuse radiation per unit area
$\mathbf{I_{dT}}$	Diffuse radiation on tilted surface
$\mathbf{I_{gT}}$	Ground reflected radiation on a tilted surface
$\mathbf{I_T}$	Total incident radiation on a flat surface per unit area
k	Thermal conductivity
$\mathbf{k_T}$	Ratio of total radiation on a horizontal surface to extraterrestrial radiation
$\mathbf{k_{tank\ wall}}$	Thermal conductivity of the tank wall
$\mathbf{M_i}$	Mass of node i
$\mathbf{\dot{m}_{down}}$	Bulk fluid flow rate down the tank
$\mathbf{\dot{m}_{up}}$	Bulk fluid flow rate up the tank
N	Number of nodes

$\mathbf{Nu_D}$	Nusselt number for external flow around a tube
$\mathbf{Q_u}$	Rate of energy gain of total collector array
$\mathbf{R_b}$	Ratio of beam radiation on tilted surface to beam on horizontal
$\mathbf{R_r}$	Ratio of reflected radiation on tilted surface to total radiation on horizontal
$\mathbf{T_a}$	Ambient temperature
$\mathbf{T_{av}}$	Average collector fluid temperature
$\mathbf{T_{env}}$	Environmental temperature for losses
$\mathbf{T_i}$	Inlet temperature of fluid to collector or, if present, heat exchanger
$\mathbf{T_i}$	Temperature of i^{th} segment
$\mathbf{T_o}$	Outlet fluid temperature of collector
$\mathbf{t}$	Time
$\mathbf{\Delta T/I_T}$	Fluid temperature minus ambient temperature divided by the incident radiation; fluid temperature may be T_i, T_{av}, or T_o
$\mathbf{\Delta x_{i+1\to i}}$	Centre-to-centre distance between node i and the node below it
$\mathbf{\Delta x_{i+1\to i}}$	Centre-to-centre distance between node i and the node above it
$\boldsymbol{\alpha}$	Solar altitude angle (90-qz)
$\boldsymbol{\beta}$	Collector slope (in degrees)
$\boldsymbol{\gamma}$	Azimuth angle of surface; angle between the projection of the normal to the surface into the horizontal plane and the local meridian. (facing equator = 0, west positive, east negative)
$\boldsymbol{\gamma}$	Control function ($0 \leq \gamma \leq 1$)
$\boldsymbol{\gamma_s}$	Solar azimuth angle
$\boldsymbol{\delta}$	Solar declination angle
$\boldsymbol{\eta}$	Overall collector efficiency
$\boldsymbol{\theta}$	Solar incident angle
$\boldsymbol{\theta_{gnd}}$	Effective incident angle for evaluating the incident angle modifier of a flat plate collector for ground reflectance radiation
$\boldsymbol{\theta_{sky}}$	Effective incident angle for evaluating the incident angle modifier of a flat plate collector for sky diffuse radiation
$\boldsymbol{\theta_Z}$	Solar zenith angle
$\boldsymbol{\rho_g}$	Ground reflectance
$\boldsymbol{\varphi}$	Latitude
$\boldsymbol{\omega}$	Mean hour angle of time step (0 at noon, mornings negative)

1 Introduction

1.1 Project Aims

This thesis simulates the domestic solar hot water heating of selected profiles for a range of commercial buildings including the demand profile associated with each. TRNSYS, a simulation program is used to model the domestic solar hot water systems for each of the commercial buildings. TRNSYS utilises Christchurch weather data in the simulation. Analysis of the simulations enables the size of the domestic solar hot water system to be economically optimised for any commercial building. This will enable designers of domestic hot water systems to confidently provide an economically optimal domestic solar hot water system for building owners to incorporate within their commercial building in Christchurch.

1.2 Background

During the design and construction of the Christchurch City Council Civic Building the building owner wanted to incorporate a domestic solar hot water system within their building. However, while undertaking the design of the domestic solar hot water system it became apparent there was a paucity of design information enabling an economically optimal solution to be incorporated. Consol New Zealand Limited imports heat pipe evacuator tube panels from Malaysia to retain around New Zealand, and their evacuator tube solar panels were installed in the Christchurch City Council Civic Building. This thesis is sponsored by Consol New Zealand Limited to support local research into solar hot water applications in New Zealand. The Consol New Zealand Limited panels were selected for this project as they were one of the highest performing evacuated tube panels available in New Zealand. As Consol New Zealand Limited is sponsoring this thesis their panels are used in the modelling, however, a sensitivity analysis was conducted to explore the effects of other panels which will be discussed.

1.3 Outline of Thesis

I firstly review the previous research conducted on domestic solar hot water and specifically explore the use of domestic solar hot water applications in the commercial sector. In addition, I review the solar hot water simulation programs capable of performing the detailed modelling required (see chapter 2).

I will then provide the technical background and theoretical detail of the simulation program TRNSYS and how it calculates the results (see chapter 3).

The design and set-out of the simulations in TRNSYS is described in Chapter 4 of the thesis, where I will discuss the specific details of the physical equipment and outline the cost of each size of domestic solar hot water system.

The detailed cost will enable a specific economic analysis to be completed on the eight commercial applications studied. The raw data from the simulations is presented and summarised in Chapter 5 and subsequently analysed which enables relationships to be identified and discussed.

Lastly I will derive conclusions stemming from the results of this research (see chapter 6), and discuss recommendations for the future (see chapter 7).

2 Literature Review

2.1 Introduction

Domestic solar hot water systems are becoming widely utilised throughout New Zealand and considered a ‘green’ technology available to home and building owners. Solar hot water is a technology regularly considered for new commercial buildings, however there is a paucity of design information available to economically optimise the size of the system.

This chapter provides a review of the current relevant literature concerning domestic solar hot water systems, specifically for commercial applications. Although, there is ongoing research in the solar industry, studies investigating the applications using domestic solar hot water a system in commercial buildings specifically is limited. There were no publications found involving commercial solar hot water application in Christchurch, New Zealand. Therefore it was decided a study should be conducted modelling domestic solar hot water systems in Christchurch analysing the energy saved. This would enable an economically optimal sized domestic solar hot water system to be designed for different commercial applications.

The following six distinct areas of literature are reviewed:

- Existing research conducted in commercial domestic solar hot water applications.

- Research completed within New Zealand for domestic solar hot water systems.

- New Zealand regulations for domestic solar hot water systems.

- Investigation of hot water demand profiles for different commercial applications.

- Reviewing research into the modelling of solar hot water systems

- Investigation into cost analysis methods used for domestic solar hot water systems

2.2 Commercial Solar Hot Water Research

While different solar hot water heaters have been designed and studied extensively over time and in the past few decades the commercial viability of solar hot water has become more recognised. This new focus has stemmed from the escalating prices of alternative energy sources the increase in quality and performance of domestic solar hot water systems.

In 1978, Thomas [1] completed a study which outlined a simplified methodology for determining the economically optimal size of solar hot water systems installed in a commercial building. Thomas utilised a simplified model to reduce the search for an economically optimal size solar system to a single deterministic equation. This introduced a new concept called universal economic optimization paths, although he identified a computer simulation model would be a valid alternative to the simplified model.

The universal economic optimisation paths were developed by linking solar and economic performance models and casting the results into an optimisation framework. Thomas bases the size of the storage tank by a proportional relationship with the solar panels area using 1.8 US gallons of water storage per ft^2 of gross collect panel (73l/m^2 of gross panel area).

Thomas concluded that the study identified an economically optimal area and fraction of hot water load to be supplied by solar as a function of annual hot water loads for different climatological areas. For any climatological area, the optimal fraction of load is independent of the load and the optimal collector area is directly proportional to the load.

In 1988 the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) released a design manual for ‘large commercial-scale solar service water and space heating systems’ [2]. The manual was developed for architects and engineers to aid them in the design of large commercial systems of at least 3,800 litres of water storage or a collector field of at least $65m^2$. While the design manual has extensive guidelines on designing a domestic solar hot water system it does not provide guidelines on economically optimising the system.

Recently localised research has been completed around the world evaluating the installation of domestic solar hot water systems in specific areas including India [3, 4], Hong Kong [5], Egypt [6], Greece [7], Senegal [8], Vietnam [9] and the United States of America [10].

2.3 New Zealand Based Solar Hot Water Research

Although research in this domain has been generally limited Gillingham [11] had conducted a study into the 'Economic efficiency of solar hot water policy in New Zealand'. Gillingham outlines the limited policy in New Zealand which is restricted to the residential market. The government provides subsidies within the residential market to encourage the installation of domestic solar hot water systems. Gillingham embraces the idea of broadening the scope of solar hot water policies to both commercial and industrial buildings. He argues this may increase the total potential for energy savings from solar hot water systems.

Lloyd and Kerr [12] studied the performance of commercially available solar and heat pump domestic water heaters in New Zealand. While their research was focused on comparing a domestic solar hot water system with electric boost to that of a heat pump system they had several key findings from their research. They recommended the government implement a subsidy program based on whole system performance as determined by TRNSYS simulations to encourage the solar hot water industry in New Zealand.

Lloyd and Kerr [13] also identified that evacuator tube product performed 1.25 times better than traditional flat plate collector in the New Zealand climate, which they noted should be considered as part of the system. While this thesis does not investigate flat plate collectors, it is important to understand in the New Zealand climate evacuator tubes traditionally perform better than flat plate panels.

In 2006, Lloyd and Kerr [13] presented a paper on experimental and simulated performance of commercially available solar and heat pump water heaters in New Zealand. They highlighted the importance of testing systems before making assumptions about energy savings and economic performance. Furthermore, they noted the high cost of installed systems in New Zealand makes it difficult for a substantial economic return. Finally, Lloyd and Kerr identified that further research was required to quantify the performance of solar hot water systems for different climatic regions in New Zealand.

2.4 New Zealand Regulations

New Zealand building regulations are enforced by the territorial authorities to ensure all buildings are constructed to standards of the current New Zealand Building Code. This includes the domestic hot water requirements in which are covered in the building code G12 - Water Supplies. In addition to the specific building code requirements for water supplies the design and installation of the solar hot water system needs to comply with the New Zealand Building Code including the following relevant sections B1 – Structure, B2 - Durability, E2 - External Moisture, H1 - Energy Efficiency, F2 - Hazardous Substances and F7 - Warning Systems.

Furthermore to the Building Code there are also national standards the design and installation must comply with. In the 1980's the Australian Standard Committee CS-028 was formed to produce standards and regulations in Australia for swimming pool solar heating systems. In the late 1990's the New Zealand Standards Committee joined the CS-028 Committee which currently produce joint standards with solar water heaters for both New Zealand and Australia. The current specific solar water heaters standards are:

- AS/NZS 4445.1:1997 Solar heating – Domestic water heating systems – Performance testing using indoor test methods which provides 'a uniform indoor test method for rating solar domestic water heating systems for thermal performance, under benchmark conditions' [14].

- AS/NZS 2535.1:2007 Testing methods for solar collectors – Thermal performance of glazed liquid heating collectors including pressure drop (ISO 9806-1:1994, MOD) which provides 'uniform test methods for the thermal performance of glazed liquid collectors' [15].

- AS/NZS 2712:2007 Solar and heat pump water heaters – Design and construction which provides 'designers, manufacturers, installers and interested parties with performance-based design and construction requirements for solar hot water supply systems' [16].

- AS/NZS 4234:2008 Heated water systems – Calculation of energy consumption which provides 'a means of evaluating the annual task performance of heated water systems' [17]. This standard requires the use of TRNSYS (version 15 or later) to complete the calculations as outlined in the standards.

In addition to the specific solar standards there is also the following standards also related to solar designs and installations:

- AS/NZS 3604:2011 Timber-framed buildings standard

- AS/NZS 1170 Structural Design Action standard
- AS/NZS 3500 Plumbing and Drainage standard
- NZS 4603:1985 Installation of low pressure thermal storage electric water heaters with copper cylinders (open-vented systems) standard
- NZS 4305:1996 Energy efficiency – Domestic type hot water systems standard.

2.5 Domestic Hot Water Load Profiles

Domestic hot water demands in a building vary as they are dependant on human behaviour. Hot water is required for washing hands, showering, cleaning, washing dishes, along with a variety of other purposes humans may have.

A study was completed by Jordan and Vajen [18] which outlines the influences of a realistic domestic hot water load profile on the energy savings of a domestic solar combisystem and the system operation (combisystems provide solar space heating and cooling as well as hot water from a single integrated system). They concluded the load profile cannot be disregarded as it has significant effects on the stratification with the storage tank. A strong influence of the domestic hot water load profile was also concluded in the studies of Knudsen [19], and Bales and Persson [20] in their respective studies of The Influence of the Thermal Performance of Small Solar Domestic Hot Water Systems and The External Domestic Hot Water Units for Solar Combisystems.

In-depth studies have been completed on estimating hot water demands to create more accurate domestic hot water load profiles for many applications (both commercial and domestic). The two most commonly used domestic hot water load profiles are produced by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the Chartered Institute of Building Service Engineers (CIBSE).

2.5.1 ASHRAE Handbook

ASHRAE is a technical society in the fields of heating, ventilation, air conditioning and refrigeration. It has a large number of members worldwide 'who share ideas, identify needs, support research, and share the industries standards for testing and practice' [21]. ASHRAE produce a four-volume handbook which cover Fundamentals, HVAC Systems and Equipment, HVAC Applications, and Refrigeration. The handbook volumes are updated on a four year cycle with one volume published each year.

Within the HVAC Applications Volume (last published in 2011) service Water Heating is specifically covered. ASHRAE utilises research in producing recovery versus storage curves for a large number of applications in which are then used to estimate different system storage capacity versus maximum plant capacity. Some of the hot water load information covered in the Service Water Heating chapter is based on limited scale field testing combined with statistical analysis to estimate load demands or diversity factors versus number of end users at a given time. The majority of the research derived to generate the diversity factors was conducted between the 1930's to 1960's, however still it is generally regarded as the best information currently available. The updated diversity factors are applied where sufficient research has been undertaken in order to validate them. The main difference in the modern day society (from when the research is completed) is the introduction of low flow and energy efficient fixtures, however, a lot more research is required before refined diversity factors can be validated. Using the older diversity factor information generally results in a water heating system that can adequately serve the loads but also can result in substantial over sizing [21].

2.5.2 CIBSE Guide

CIBSE is a British professional engineering body based in London, England that represents building service engineers. It is a professional body that exists to 'support the science, art and practice of building service engineering, by providing our members and the public with first class information and education services and promoting the spirit of fellowship which guides our work' [22].

CIBSE produce guidelines to aid building service engineers in designs, which are updated periodically when significant changes are made. CIBSE Guide G – 'Public Health Engineering' has a section on 'Water Services and Utilities' which was last published in 2004. The CIBSE guide categorises the application and gives guidance to the time of the recovery period for the certain application. Each application has a system curve in which selected recovery period will give a corresponding system heat capacity (i.e. boiler size) and a hot water storage capacity. The system curves are based off an existing British Standard (BS6700) and research completed and outlined in the Plumbing and Engineering Services Design Guide [23].

2.6 Modelling of Solar Hot Water Systems

There are a number of design methods for solar hot water systems from detailed transient thermal performance calculations for detailed analysis to methods for substituting the detailed analysis with relationships based on many numerical experiments.

Sheridan, Bullock and Duffie [24] completed a study in 1967 of solar processes by an analog computer. They concluded that process analysis will contribute to an improved understanding of the relationship among component and result in more rational designs. This research led to the start of computer based programs to complete modelling of solar hot water systems (as well as other solar based systems).

TRNSYS [25] is a widely used transient process simulation program with a modular structure. Initially TRNSYS was developed to save time. Instead of writing a monolithic program to model the entire solar energy systems TRNSYS writes a series of programs, each of which models a single component to complete the calculations. This enables the user to easily change parameters within the calculation and rerun the program.

TRNSYS is widely recognised as the most accurate and complete design tool available (Garg [26]). To justify this Garg [26] studied 'An Overview of Design Methods for Solar Water Heating Systems' which outlined other commonly used domestic solar hot water simulation programs including the F-chart method, SOLCOST program, SLR method and the SEU method all in comparison to a TRANSYS program (TRNSYS).

TRNSYS is regularly used to complete simulations for research in solar applications. These include more recent studies (but not limited to) completed by Chow [5], Hobbi [27], Raffenel [28], Lima [29], Yohanis [30] and Spur [31].

2.7 Economic Analysis of Solar Domestic Hot Water Systems

Domestic solar hot water systems are generally characterised by high capital cost and low operating costs. Thus, the economic analysis is comparing the initial capital outlay versus the energy saving over a given period. Most domestic solar hot water systems require an additional auxiliary heat source to provide the additional heating requirements when the solar energy is insufficient. Therefore, the annual domestic hot water load is met by the combination of the solar energy and auxiliary heat source.

Duffie and Beckman [32] dedicate a chapter to solar process economics in their text book 'Solar Engineering of Thermal Processes'. While the details are based on the American tax system they outline six separate economic criteria for evaluating and optimising solar energy systems. The six economic criteria outlined are:

- **Least cost solar energy** used to evaluate when only solar energy is used (no auxiliary back-up).

- **Life-cycle cost (LCC)** used to evaluate all costs associated with a solar hot water system over its lifespan in 'today's dollars' including taking into account the time value of money.

- **Life-cycle savings (LCS)** used to evaluate the life cycle cost of the conventional no solar system and the life cycle cost of the solar plus auxiliary energy system.

- **Annualised life-cycle cost (ALCC)** used to evaluate the average yearly cashflow and evaluates against the cost of installing the system based on paying the system off in equal payments in today's dollars over the period of the systems life.

- **Annualised life-cycle savings (ALCS)** used to evaluate the yearly savings and evaluates against the cost of installing the system in today's dollar over the period of the systems life.

- **Payback time** used to evaluate solar in several different ways but most commonly is the time needed for the fuel savings to equal the total initial investment.

Gladius [33] investigated the economic analysis methods and evaluated each method. While each of the methods had different approaches they were all found to be comparable. However, it was noted for each of the methods to be comparable, inflation rate of the auxiliary energy was required and needed to be accounted for.

2.8 Discussion

While there has been numerous studies completed in the field of domestic solar hot water systems, as outlined it has only been in more recent times that commercial application based research has been conducted. The existing studies outlined several key ideas that assist in forming a detailed study in applying domestic solar hot water systems in commercial applications.

Specific research in New Zealand is limited, and there is a need to complete studies to quantify solar hot water systems specifically for different climatic regions in New Zealand.

Thomas [1] and the Australian and New Zealand Standards outline a relationship between the size of the storage tank and the number of panels (73l per square meter of gross panel area and 50l per square meter of net panel area respectively). This relationship will assist with defining system sizes to enable an economic analysis to be completed.

Thomas [1] also concluded in his study (optimisation paths for solar hot water systems in commercial buildings) that for any climatological area the optimal fraction of load for servicing with solar is independent of the total load, and that the optimal collector area is directly proportional to the total load.

Jordan and Vajen [18], Knudsen [19] and Bales and Persson [20] all conclude in their studies the importance of the domestic hot water load profile in regards to the influence it has on the domestic solar hot water system.

The Australian and New Zealand Standards only accept TRNSYS to simulate the domestic solar hot water system and numerous studies have been completed using this software package.

Although multiple methods to complete an economic analysis are available, this study will conduct the economic analysis using a life cycle cost calculation to identify the savings achieved by the domestic solar hot water system. In addition, an inflation rate will also be used as recommended for the cost of energy.

In conclusion, further research is required with modelling commercial domestic solar hot water application in Christchurch New Zealand. This is particularly relevant due to the amount of commercial buildings that will be required to be constructed subsequent to recent earthquake activity. This study will utilise the evacuator tube solar hot water panels in a domestic solar hot water systems to economically optimise the size of the system for different commercial applications.

3 Simulation Background

3.1 Introduction

This section outlines the background of the design, setup and simulations undertaken to economically optimise the domestic solar hot water system for commercial applications in Christchurch. A numerical simulation was established along with the system parameters using the TRNSYS program. With the TRNSYS simulation an analysis of each commercial application enabled an economic analysis to be completed.

3.2 Design of Simulation

3.2.1 Computer Simulation

A set of simulations were designed to simulate a domestic solar hot water system. The simulations needed to enable an evaluation of a relationship of the size of the commercial application and the size of the system required. Each commercial application requires a domestic hot water profile that reflects the size of the building, and its use.

3.2.2 System Setup

To achieve a relationship for the domestic solar hot water, key parameters need to be changed (size of the storage tanks and the number of panels).

The storage tanks and the number of panels have a proportional relationship of 50l per square meter of net panel area.

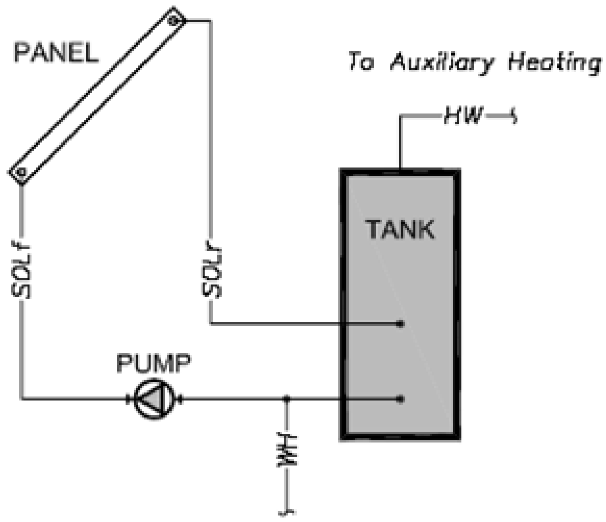

Figure 3-1: Base system schematic for domestic solar hot water.

Figure 3-1 illustrates the basic system schematic of the domestic solar hot water setup. The number of panels and storage tank change proportionality to set the size of the system. Other parameters are all held constant or are based on the relationship to the number of panels and of the size of the storage tank. The parameters that change include the pump flow rate, which is based on the number of panels with a larger pump used for larger systems. In addition the pipe length is based on 10 metres from the panels with 5 metres added for each panel and the size of the pipe based on a maximum of 300Pa/m of friction loss (The pipe is made of copper and encased with 25mm thick closed cell insulation).

3.3 TRNSYS Simulation Overview

The TRNSYS simulation was created using the IISiBat (Intelligent Interface for the Simulation of Buildings) program [34]. The IISiBat program is a graphical interface that provides access to the TRNSYS simulation engine. Components (known as a TYPE) are placed in the IISiBat assembly panel. Each component has its own sub-routine calculations that are performed. Each component requires inputs and parameters which enable the subroutine calculations to be carried out and produce outputs. The output from one component may need to be used as an input for another component which is completed by linking the components together in the IISiBat panel.

The following components were used in the simulation and will be outlined in subsequent sections:

- TYPE 1 flat plate collector
- TYPE 2 on/off differential controller
- TYPE 3 pump
- TYPE 6 auxiliary heater
- TYPE 14 time dependent forcing function (2 off.)
- TYPE 16 solar radiation processor

- TYPE 24 quantity integrator
- TYPE 25 printer
- TYPE 31 pipe or duct (2 off.)
- TYPE 60 stratified fluid storage tank
- TYPE 65 online graphics (2 off.)
- TYPE 89 formatted file data reader

Each component serves a specific purpose in the simulation are linked together to complete the simulation. Figure 3-2 and Figure 3-3 illustrate the flow between each of the components and the links formed in the model. Refer to Appendix A for details of the components inputs and outputs.

The flow charts of components (Figure 3-2 and Figure 3-3) are used in IISiBat to connect them together using the inputs and outputs from each component. Figure 3-4 below is a screen shot from IISiBat assembly panel which visually illustrates the connections between the components.

The basis of the simulation follows the guidelines of the Australian and New Zealand Standard AS/NZS 4234:2008 Heated water systems – Calculations of energy consumption.

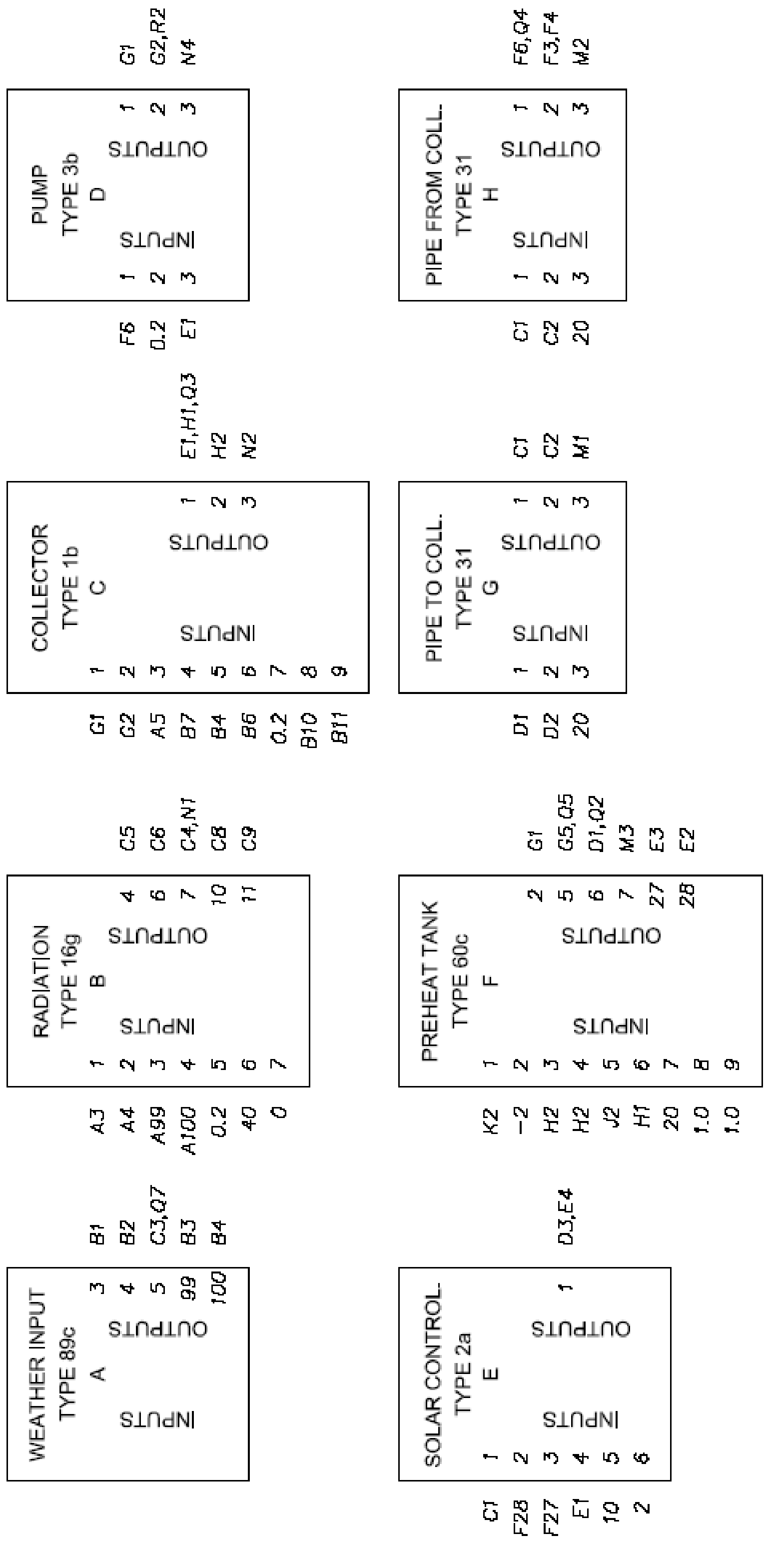

Figure 3-2: Flow chart of the components (1 of 2).

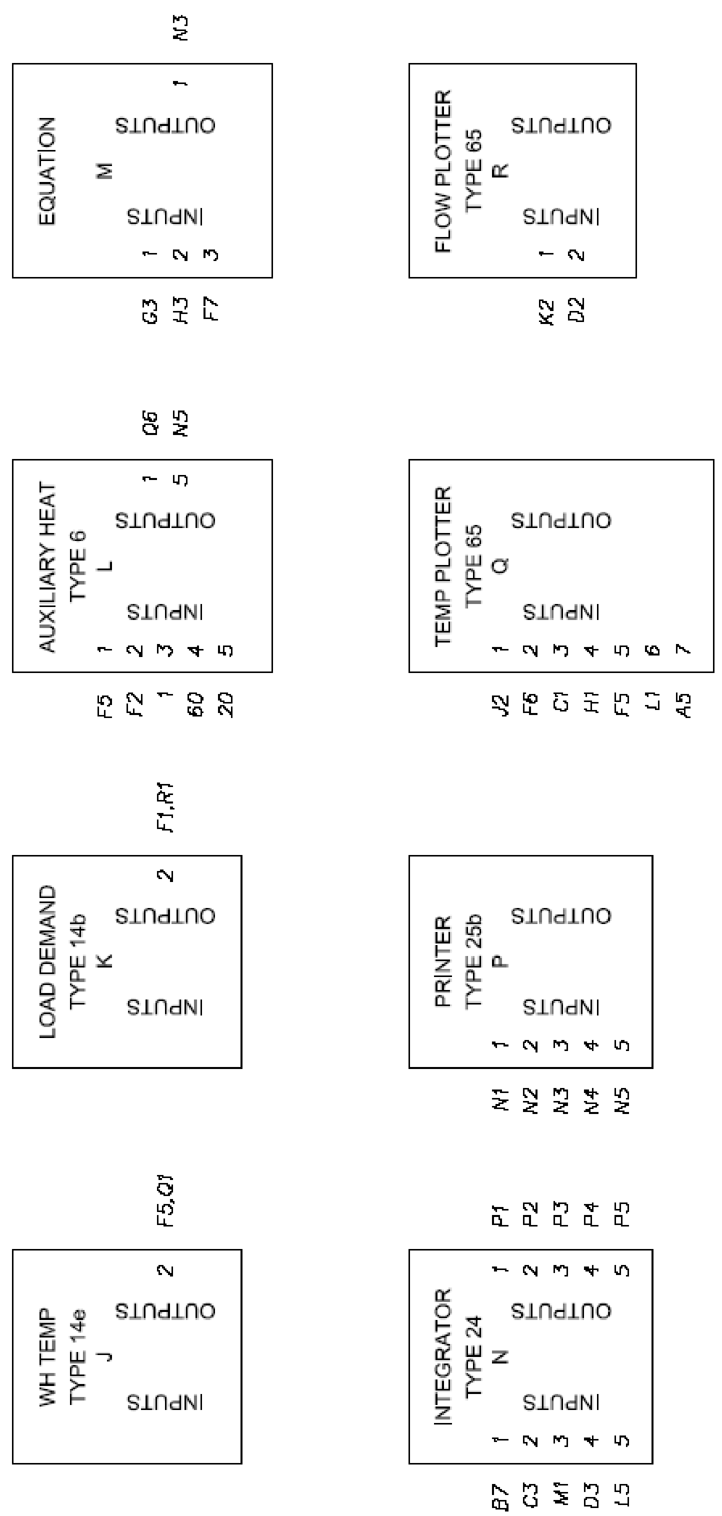

Figure 3-3: Flow chart of the components continued (2 of 2).

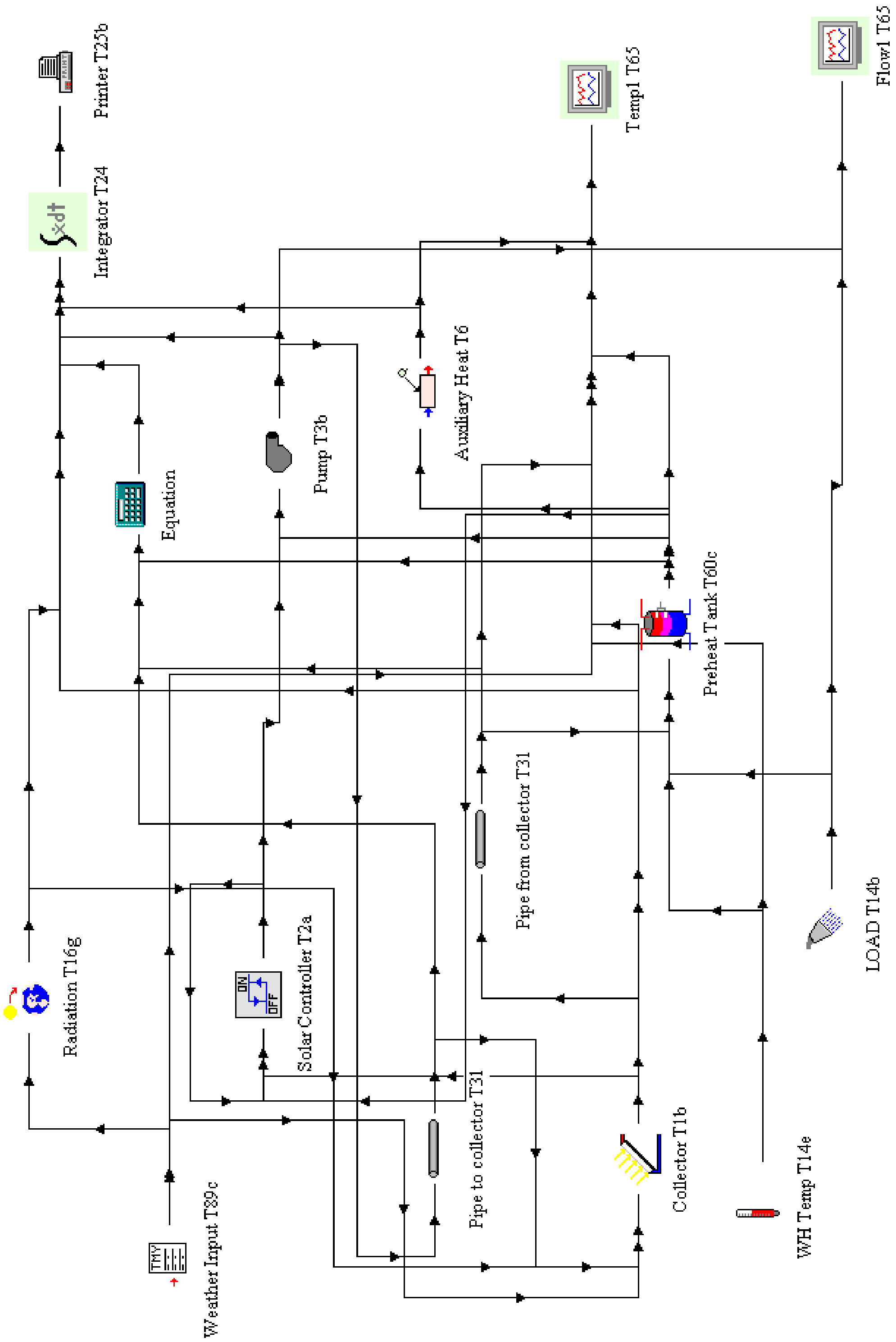

Figure 3-4: IISiBat assembly panel.

3.4 TRNSYS Component Details

The following section outlines the details of each component used in the model. All information regarding the components is from the TRNSYS reference manual [34].

3.4.1 Type 1 Flat Plate Solar Collector

The flat plate solar collector models and the thermal performance of evacuator tube (or flat plate solar collectors) can be modelled in series or parallel. In order for the simulations to be completed, standard test results must be provided for the collector efficiency curve. The collector efficiency curve is used to represent the thermal performance of the collectors. The Australian and New Zealand standard AS/NZS 2535.1:2007 outlines the testing procedures for obtaining the collector efficiency curve for a solar panel. The only approved test facility currently in New Zealand is the Applied Research Services Limited set up in Nelson. Consol New Zealand Limited's evacuator tube solar collectors were tested in August 2010 (see the test report in Appendix B). The standard test results provide the following input:

- Efficiency versus a ratio of fluid temperature minus ambient temperature to radiation. The fluid temperature may be an inlet, average, or outlet temperature.

The energy gained by the heat transfer fluid (water) as it passes through the solar collector is the difference between the solar energy that is absorbed and the energy lost by the collector to the surroundings. The efficiency of the collection (η) is the ratio of collected useful energy to incident solar energy on the collector, which can be obtained from the Hottel-Whillier equation as:

$$\eta = \frac{Q_u}{AI_T} = F_R(\tau\alpha) - F_R U_L \frac{(T_i - T_a)}{I_T} \qquad (3\text{-}1)$$

Collector efficiency tests are generally presented as straight line plots of η versus $(T_i\text{-}T_a)/I_T$ with intercept of $F_R(\tau\alpha)_n$ and slope $-F_RU_L$. However, the characteristic is often a curve rather than a straight line because the heat loss coefficient is not a constant. Extending (3-2) the curve can be modelled with a quadratic approach. The collector characteristics F_R, $(\tau\alpha)$ and U_L may therefore be estimated from the efficiency quadratic derived from test results.

$$\eta = \frac{Q_u}{AI_T} = F_R(\tau\alpha) - F_R U_L \frac{(T_i - T_a)}{I_T} - F_R U_{\frac{L}{T}} \frac{(T_i - T_a)^2}{I_T} \qquad (3\text{-}3)$$

Alternatively,

$$\eta = \frac{Q_u}{AI_T} = a_0 - a_1\frac{(T_i - T_a)}{I_T} - a_2\frac{(T_i - T_a)^2}{I_T} \tag{3-4}$$

The testing procedure outlined in the standards provides the three coefficients for the intercept and slope of the efficiency versus $(T_i-T_a)/I_T$, $(T_{av}-T_a)/I_T$, or $(T_o-T_a)/I_T$.

Other analytical corrections [32] are applied to the collector parameters to account for the following:

- Operation at flow rates other than the value at test conditions
- A number of collectors mounted in series
- Non-normal solar incidences

Collector tests are generally performed on clear days at normal incidence so that the transmittance – absorptance product is nearly the normal incident value for beam radiation, $(\tau\alpha)_n$. The intercept efficiency, $F_R(\tau\alpha)_n$, is corrected for non-normal solar incidence by the factor $(\tau\alpha)/(\tau\alpha)_n$. By definition, $(\tau\alpha)$ is the ratio of the total absorbed radiation to the incident radiation.

Thus, a general expression for $(\tau\alpha)/(\tau\alpha)_n$ is:

$$\frac{(\tau\alpha)}{(\tau\alpha)_n} = \frac{I_{bT}\frac{(\tau\alpha)_b}{(\tau\alpha)_n} + I_d\left(\frac{1+\cos\beta}{2}\right)\frac{(\tau\alpha)_s}{(\tau\alpha)_n} + \rho_g I\left(\frac{1+\cos\beta}{2}\right)\frac{(\tau\alpha)_g}{(\tau\alpha)_n}}{I_T} \tag{3-5}$$

For flat-plate collectors, $(\tau\alpha)_b/(\tau\alpha)_n$ can be approximated from test results as:

$$\frac{(\tau\alpha)_b}{(\tau\alpha)_n} = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) - b_1\left(\frac{1}{\cos\theta} - 1\right)^2 \tag{3-6}$$

In accordance to the AS/NZS 4234:2008 b_0 shall be 0.06 for evacuated tubes as a default. This is used as an incident angle modifier for the round evacuator tubes when the sun is not perpendicular to the panels.

The incidence angle modifiers for both sky, $(\tau\alpha)_s/(\tau\alpha)_n$ and ground diffuse $(\tau\alpha)_g/(\tau\alpha)_n$, are determined by defining equivalent incidence angles for beam radiation that give the same transmittance as for diffuse radiation [32]. The effective incidence angles for sky diffuse (θ_{sky}) and ground reflectance (θ_{gnd}) are:

$$\theta_{sky} = 59.68° - 0.1388\beta + 0.001497\beta^2 \tag{3-7}$$

$$\theta_{gnd} = 90° - 0.5788\beta + 0.002693\beta^2 \tag{3-8}$$

3.4.2 *Type 2 On/Off Differential Controller*

An on/off differential controller is used to control the pump and domestic solar hot water system. The controller generates a control function γ_o that can have values of 0 or 1. The value of γ_o is chosen as a function of the difference between upper and lower temperatures (T_H and T_L) and compared with two presented dead band temperatures differences (ΔT_H and ΔT_L) which are set to 8 degrees Celsius and 2 degrees Celsius respectively. The new value of γ_o is dependent on whether γ_i=0 or 1. For safety reasons, a high limit cut-out is included. The controller monitors the temperature differential from the solar panels to the storage temperature and switches the pump on when there is a positive temperature differential.

3.4.3 *Type 3 Pump*

This pump component computes a mass flow rate using a variable control function, which must be between 0 and 1, and a fixed (user specified) maximum flow capacity. Pumps power consumption may also be calculated, either as a linear function of mass flow rate or by a user-defined relationship between the mass flow rate and power consumption.

The pumps used are fixed speed pumps and the value given by the controller is either a 0 (pump off) or 1 (pump on at full power).

3.4.4 *Type 6 Auxiliary Heater*

An auxiliary heater is modelled to elevate the temperature of the flow-stream to the set point when the solar hot water system does not meet the set point. The auxiliary heater is controlled to ensure the supply temperature is 65 degrees Celsius. The additional energy consumed is outputted for monitoring.

3.4.5 *Type 14 Time Dependent Forcing Function*

In transient simulations, it is sometimes convenient to employ a time-dependent forcing function which has a behaviour characterised by a repeated pattern. The purpose of this routine is to provide a means of generating a forcing function of this type. The pattern of the forcing function is established by a set of discrete data points indicating its value at various times through one cycle. Linear interpolation is provided in order to generate a continuous forcing function from this discrete data.

Two time dependent forcing functions are used to control the cold water temperature and the daily hot water demand profile.

3.4.6 *Type 16 Solar Radiation Processor*

This component interpolates the radiation data from the weather files, calculates several quantities related to the position of the sun, and can estimate the insolation on the solar panels.

The solar radiation processor utilises the weather data from the formatted data reader to calculate total radiation between two time steps. Finally, the total radiations between the hours of time steps are derived by summing the integrals.

TYPE 16 obtains beam and diffuse radiation on a horizontal surface from the total radiation on a horizontal surface data. Horizontal radiation is based on the relationships developed by Reindl [32] and provides estimates of the diffuse fraction of the horizontal radiation (I_d/I). It reduces the form of the full correlation using the clearness index and the solar altitude angle to estimate the diffuse fraction. The correlation is given by the following equations:

$$\frac{I_d}{I} = \begin{cases} 1.020 - 0.254k_T + 0.0123\sin(\alpha) & \text{for } 0 \leq k_T \leq 0.3 \\ 1.400 - 1.749k_T + 0.177\sin(\alpha) & \text{for } 0.3 < k_T < 0.78 \\ 0.486k_T - 0.182\sin(\alpha) & \text{for } 0.78 < k_T \end{cases} \tag{3-9}$$

The beam radiation on a horizontal surface is calculated by the difference between the total radiation and the diffuse component:

$$I_b = I - I_d \tag{3-10}$$

The position of the sun in the sky can be specified by giving the solar zenith and solar azimuth angles. Both the zenith and solar angles can be determined from trigonometric relationships:

$$\cos\theta_Z = \sin\delta\sin\varphi + \sin\varphi\cos\delta\cos\omega \quad (3\text{-}11)$$

$$\sin\gamma_s = \frac{\cos\delta\sin\omega}{\sin\theta_Z} \quad (3\text{-}12)$$

The total tilted surface radiation is calculated by estimating and adding the beam, diffuse, and reflected radiation components on the tilted surface. The contribution of beam radiation on a tilted surface (in short time intervals) can be calculated by using the geometric factor R_b:

$$R_b = \frac{\cos\theta}{\cos\theta_Z} \quad (3\text{-}13)$$

where:

$$\cos\theta = \cos\theta_Z\cos\beta + \sin\theta_Z\cos(\gamma_s - \gamma)\sin\beta \quad (3\text{-}14)$$

$$I_{bT} = I_b . R_b \quad (3\text{-}15)$$

The contribution of reflected radiation on a tilted surface is calculated by assuming that the ground acts as an isotropic reflector. R_r is defined as the ratio of reflected radiation on a tilted surface to the total radiation on a horizontal surface which is:

$$R_r = 0.5(1 - \cos\beta)\rho_g \quad (3\text{-}16)$$

$$I_{gT} = I . R_r \quad (3\text{-}17)$$

The Reindl Model is utilised to derive the contribution of diffuse radiation on a tilted. The Reindl Model accounts for the circumsolar and isotropic diffuse radiation, in addition to a horizontal brightening diffuse term. The Reindl tilted surface diffuse radiation model is given by:

$$f = \sqrt{\frac{I_b}{I}} \tag{3-18}$$

$$I_{dT} = I_d \left[0.5(1 - A_I)(1 + \cos\beta)\left(1 + (f)\sin^3\left(\frac{\beta}{2}\right)\right) + A_I R_b \right] \tag{3-19}$$

Thus, the total radiation incident on a tilted flat surface for all tilted surface radiation modes is:

$$I_T = I_{bT} + I_{dT} + I_{gT} \tag{3-20}$$

3.4.7 Type 24 Quantity Integrator

This component is used to integrate a quantity over a period of time and calculates the total. This enables total sums for pumping energy, solar, amount of solar collected, heat losses from the system and amount of auxiliary energy summed annually.

3.4.8 Type 25 Printer

This component is used to output variables from the integrator, which are analysed after the simulation.

3.4.9 *Type 31 Pipe or Duct*

This component models the thermal losses in the pipe. The AS/NZS 4234:2008 requires 10 metres of pipe losses to be modelled from the solar panels. To allow installation 5 metres of pipe are used per panel. Locally available copper pipe is used and sized based on a frictional loss maximised at 300Pa/m. The pipe is insulated using 30mm of closed cell insulation.

3.4.10 *Type 60 Stratified Fluid Storage Tank*

This component models the thermal performance of a water-filled sensible energy storage tank, subject to thermal stratification, by assuming the tanks consists of N ($N \leq 100$) fully-mixed equal volume segments. The degree of stratification is determined by the number of nodes (the value of N). If N is equal to 1, the storage tank is modelled as a fully mixed tank and no stratification effects are possible. The AS/NZS 4324:2008 calls for a minimum of 20 nodes to be used to accurately model thermal stratification in controlled flow pumped systems.

The maximum standing heat loss of the tank wall is set based on the minimum standards according to the New Zealand Standard NZS4606.1:1989. This sets the maximum heat for a cylinder as:

$$q = 0.0084\,L + 0.40 \qquad \text{for } L<90 \qquad (3\text{-}21)$$

$$q = 0.0048\ L + 0.82 \qquad \text{for } L>90 \qquad (3\text{-}22)$$

To model de-stratification due to mixing at or between node interfaces and conduction along the tank wall, an additional conductivity parameter Δk is required. The additional conductivity term is added to the conductivity of the tank fluid and is applied to all nodes. This may be estimated by:

$$\Delta k = k_{tank\ wall} \frac{A_{c,tank\ wall}}{A_{c,water}} \qquad (3\text{-}23)$$

where $k_{tank\ wall}$ is the thermal conductivity of the tank wall and A_c is the cross-sectional area.

An energy balance written about the i[th] tank segment is expressed by combining all energy flows into one equation. The differential equation for the temperature of node i is expressed as:

$$\begin{aligned}(M_i C_p)\frac{dT_i}{dt} &= \frac{(k+\Delta k)A_{c,i}}{\Delta x_{i+1\to i}}(T_{i+1}-T_i) + \frac{(k+\Delta k)A_{c,i}}{\Delta x_{i+1\to i}}(T_{i-1}-T_i) \qquad (3\text{-}24)\\ &+ (U_{\tan k} + \Delta U_i)A_{s,i}(T_{env}-T_i) + \dot{m}_{down}C_p(T_{i-1}) - \dot{m}_{up}C_p(T_i)\\ &- \dot{m}_{down}C_p(T_i) - \dot{m}_{up}C_p(T_{i+1}) + \dot{m}_{1in}C_pT_{1in} - \dot{m}_{1out}C_pT_i\\ &+ \dot{m}_{2in}T_{2in} - \dot{m}_{2out}C_pT_i\end{aligned}$$

The temperatures of each N tank segments are determined by the integration of their time derivatives expressed in the above equation. At the end of each time step, temperature inversions are eliminated by mixing approximate adjacent nodes.

The outside natural convection coefficient h_o is determined from:

$$\boldsymbol{h_o} = \frac{Nu_D(k)}{d_o} \tag{3-25}$$

where

$$Nu_D = CRa^n \tag{3-26}$$

3.4.11 Type 65 Online Graphics

This component analyses data during the simulation which enables temperatures throughout the system to be analysed in real time.

3.4.12 Type 89 Formatted File Data Reader

This component reads meteorological data at regular time intervals from a premade file format with specific inputs. It is designed to read a number of different file formats and is expandable so other file formats can be added.

Typical Meteorological Year (TMY) weather information is the most commonly used weather file for TRNSYS. Each TMY file contains one complete year of weather information, at one hour time intervals. The TMY files are either created from thirty years of measured solar radiation and temperatures, or are generated based on other measured meteorological phenomena to genuine data sites using a correlated model.

Currently, the only information they have available in New Zealand is the city of Wellington. However, a Christchurch weather file can be created by averaging weather from 2004 to 2009 from local measured meteorological data (supplied from NIWA database) with the data fields to create a suitable TMY file:

Table 3-1: Modified TRNSYS TMY Data Fields

TMY FIELD #	COLUMN #	FIELD
1	2-3	Month of the year
2	5-7	Hour of the month
3	10-13	Direct normal collar radiation integrated over previous
4	15-18	Global solar radiation on horizontal surface, integrated
5	20-23	Dry bulb temperature, degrees*10°C
---	25-30	Humidity ratio *10,000
6	32-33	Wind velocity, m/s
7	35-36	Wind direction

3.5 Domestic Cold Water Temperature

The domestic cold water temperatures used align with the Australian and New Zealand Standards AS/NZS 4234:2008.

Table 3-2: Cold Water Temperature (°C)

Month	Temperature (°C)
January	16
February	16
March	15
April	11
May	9
June	6
July	5
August	6
September	8
October	11
November	13
December	15

3.6 Domestic Hot Water Load Profiles

A load profile predicts how much hot water is used in certain applications. There are different load profiles for each application, from domestic to commercial, as they vary greatly. The following section outlines the load profiles for commercial applications that will be used. The following commercial applications will be investigated:

- Motels and Hotels
- Apartments
- Retirement Homes
- Offices
- Restaurants and Cafes

- Fast Food Restaurants
- Primary Schools
- Secondary Schools

The load profiles will outline the commercial application that will be investigated to economically optimise the domestic solar hot water system.

The ASHRAE load profile will be used for TRNSYS modelling. ASHRAE looks at average hot water consumption per unit (depending on the type of building). The average water profile is subsequently broken down to a percentage of water consumed over each hour, compared to the whole day. Each application has an expected daily water consumption based on the applications units (such as number of meals served or number of rooms etc). Further, the percentage of water used can be multiplied to provide the hourly breakdown of water usage.

The following sections will outline each of the commercial applications domestic hot water profiles, including the hourly break down.

3.6.1 *Motels and Hotels*

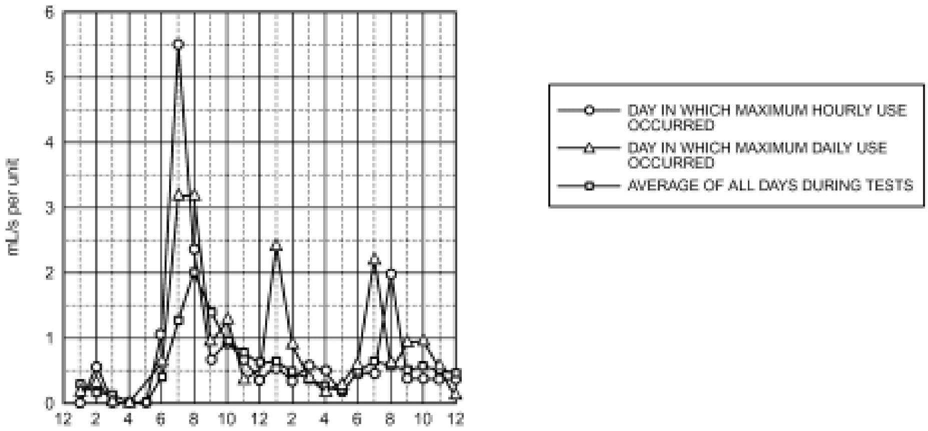

Figure 3-5: Hourly domestic hot water flow profile for Motels and Hotels [21]

Domestic hot water requirements for motels and hotels generally include showers, wash hand basins and general cleaning. There is a distinct peak demand with the use of showers in the morning. However, food services, laundries, and swimming pool requirements are not included within this domain.

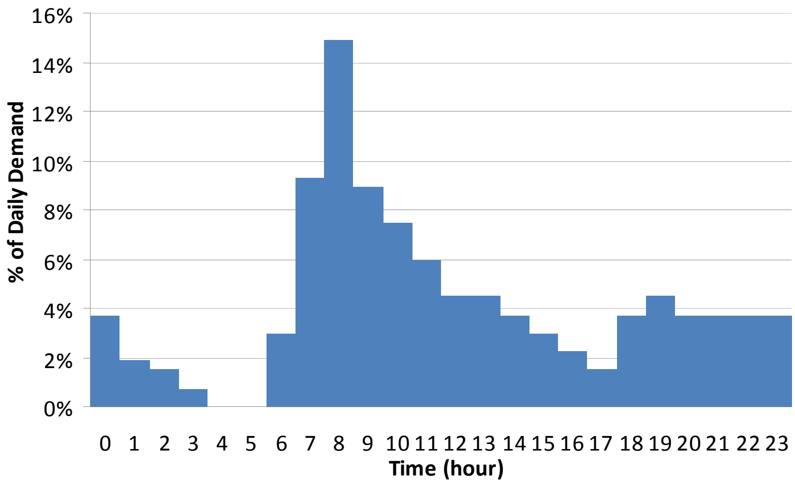

Figure 3-6: Daily domestic hot water load profile for Hotels and Motels

The average daily water demand is based on the number of beds available in the hotel/motel. For twenty beds or less the average consumption of hot water is 75 litres per bed. Whereas, for twenty one to ninety nine beds the average consumption of hot water falls to 60 litres per bed, and for one hundred or more beds the average consumption of hot water falls to 50 litres per bed.

3.6.2 Apartments

Domestic hot water requirements include garden type and high rise apartments. It covers general living water use such as bathing, cleaning, dishwashing and laundry (either individual or centrally located laundry facilities). Apartments generally have two or three bedroom per unit.

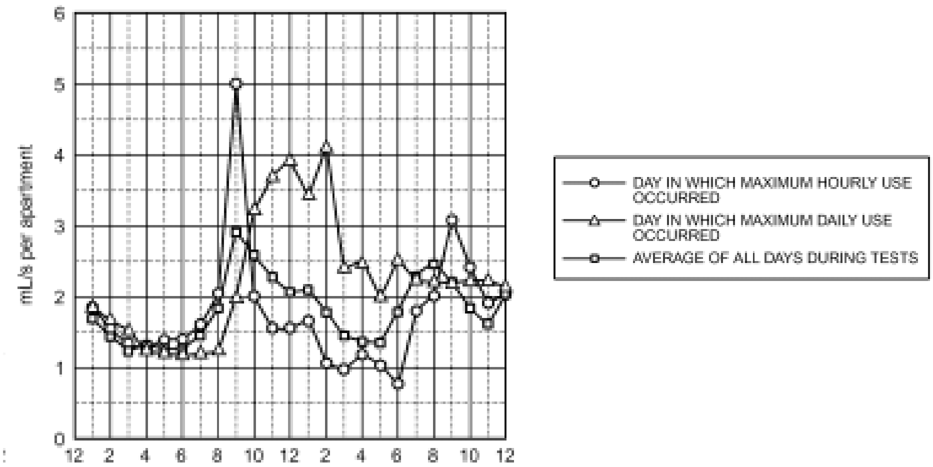

Figure 3-7: Hourly domestic hot water flow profile for Apartments [21]

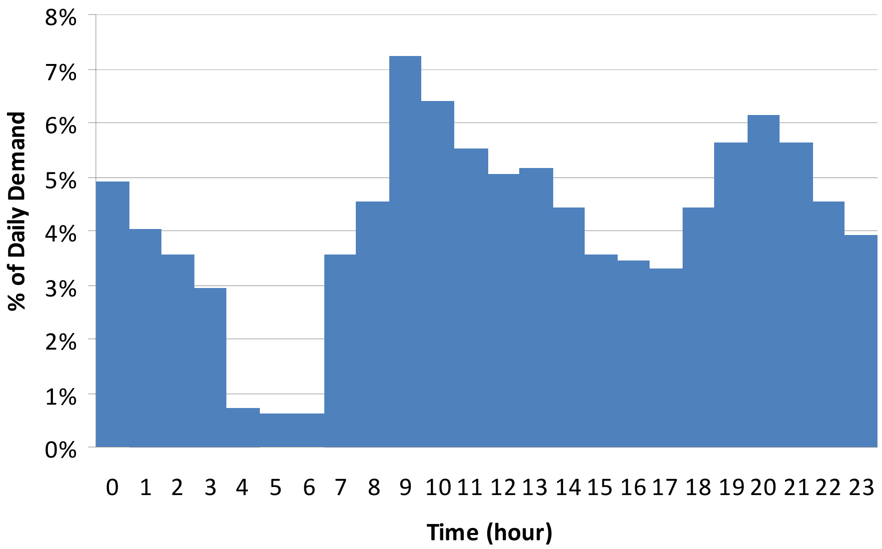

Figure 3-8: Daily domestic hot water load profile for Apartments

The average daily water demand is based on the number of apartments in a single complex (running off a central water system). For twenty or less apartments the average consumption of hot water is 200 litres per apartment. However the average consumption of hot water falls to 180 litres per apartment for apartments ranging between twenty one to ninety nine. For one hundred or more apartments the average consumption of hot water falls to 150 litres per apartment.

3.6.3 Retirement Homes

Domestic hot water requirements within retirement homes include bathing, showering, wash hand basins, service sinks, kitchen equipment, hot water use in the kitchen and general cleaning. However, it does not include for domestic hot water use for onsite commercial laundry services.

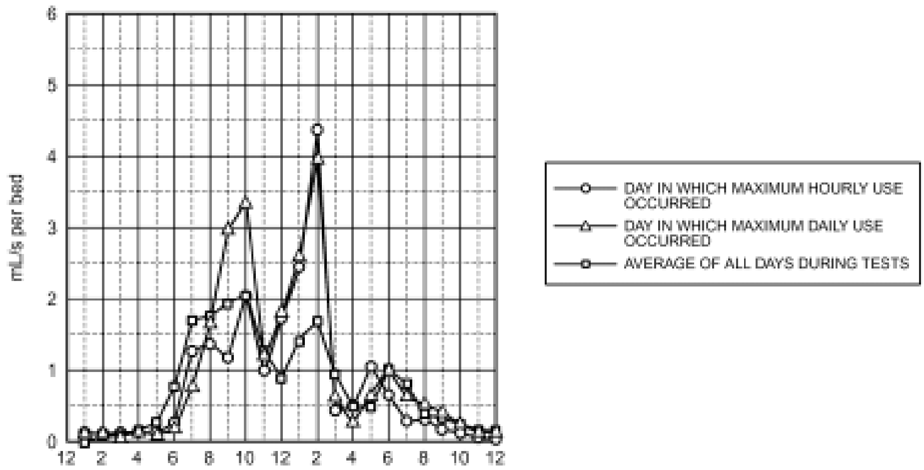

Figure 3-9: Hourly domestic hot water flow profile for Retirement Homes [21]

The average daily water demand is based on the number of beds in a retirement home with an average domestic hot water consumption of 70 litres per bed.

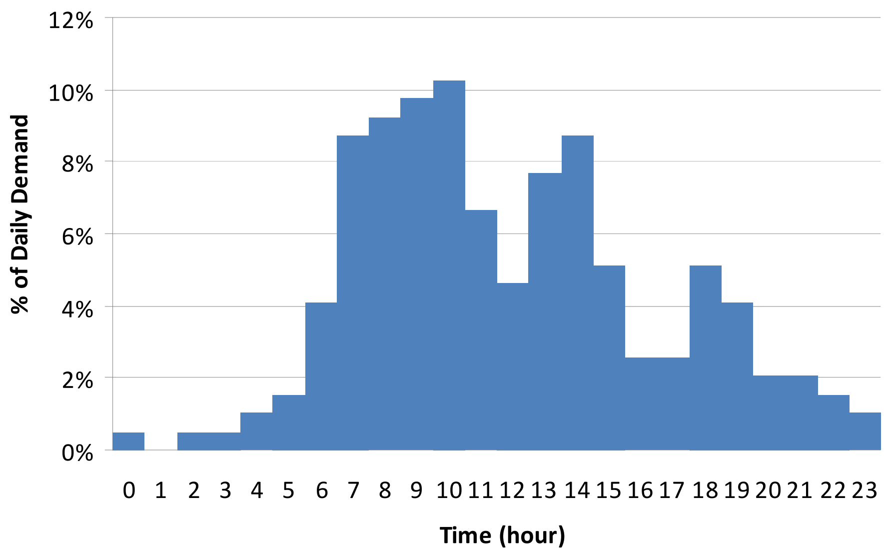

Figure 3-10: Daily domestic hot water load profile for Retirement Homes.

3.6.4 Offices

Domestic hot water requirements in offices are primarily for cleaning and toilet use the occupants and visitors; however do not include an onsite food service establishment.

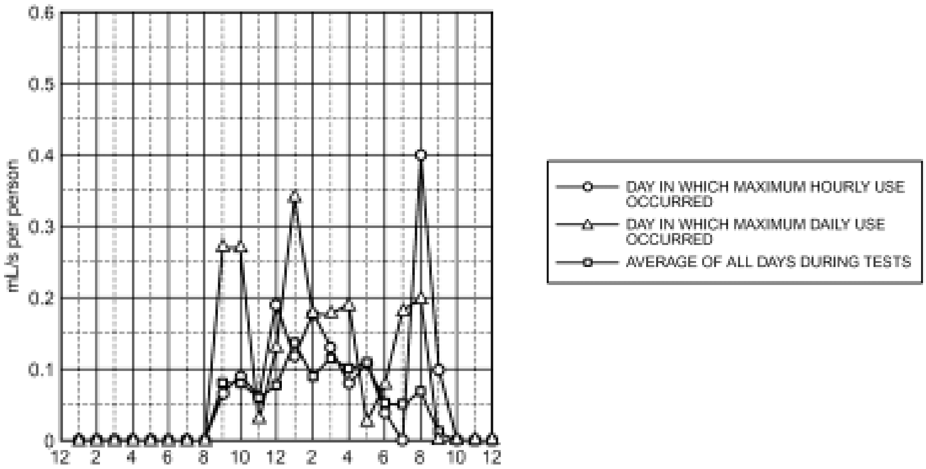

Figure 3-11: Hourly domestic hot water flow profile for Offices [21]

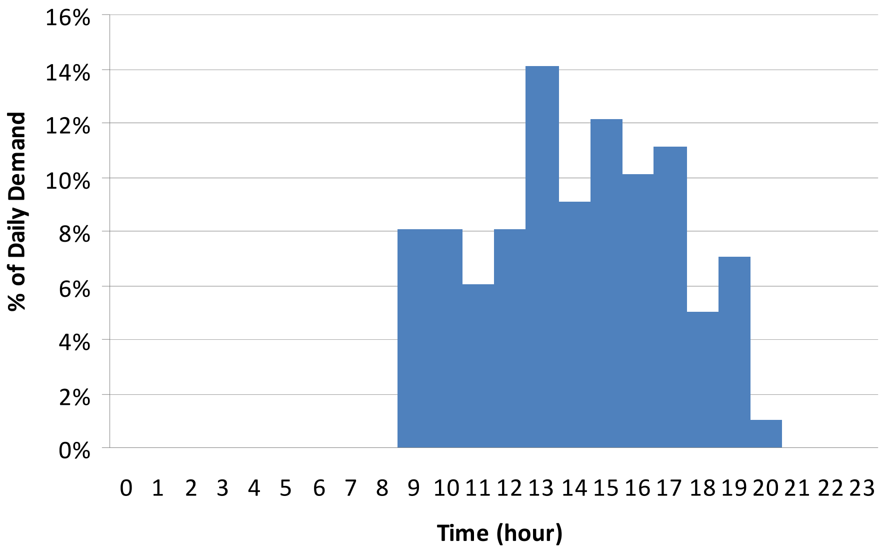

Figure 3-12: Daily domestic hot water load profile for Offices

The average daily water demand is based on the number of people in the office with an average domestic hot water consumption of 6 litres per person.

3.6.5 Restaurants and Cafes

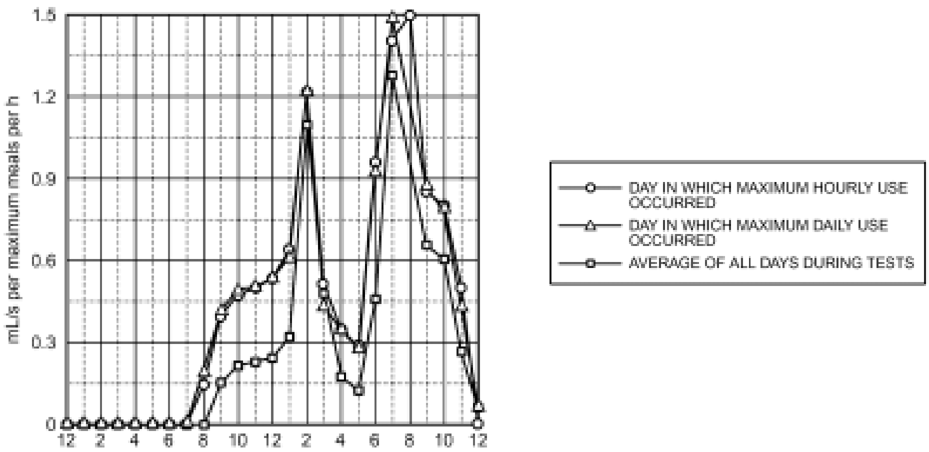

Figure 3-13: Hourly domestic hot water flow profile for Restaurants and Cafes [21]

Restaurants and Cafes are where customers generally purchase and consume food. Domestic hot water requirements for restaurants and cafes primarily include dishwashing, food preparation, hand washing and cleaning.

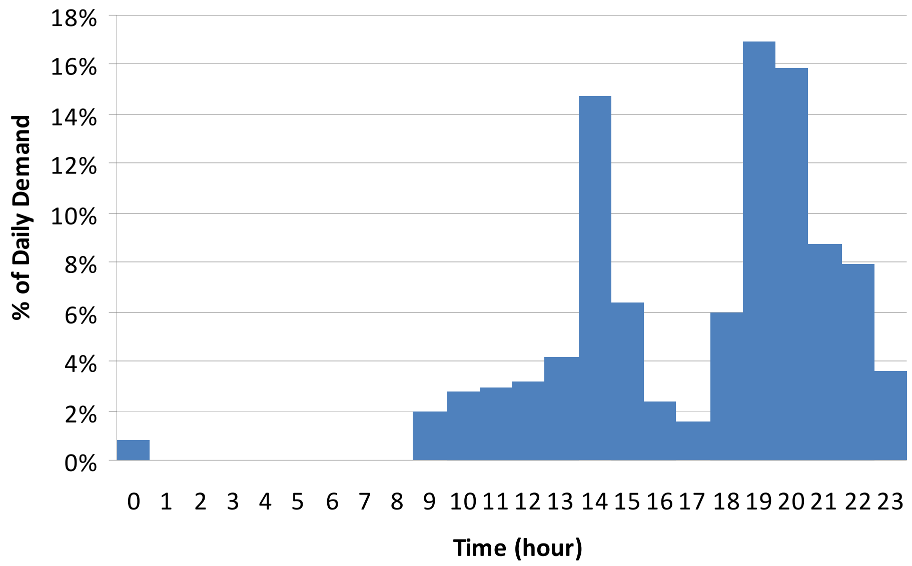

Figure 3-14: Daily domestic hot water load profile for Restaurants and Cafes

The average daily water demand is based on the number of meals served at the Restaurant or Cafe with an average domestic hot water consumption of 15 litres per meal served.

3.6.6 Fast Food Restaurants

Fast Food Restaurants is where the customers generally purchase the food and take the food away. Domestic hot water requirements within this domain include dishwashing, food preparation, hand washing and cleaning.

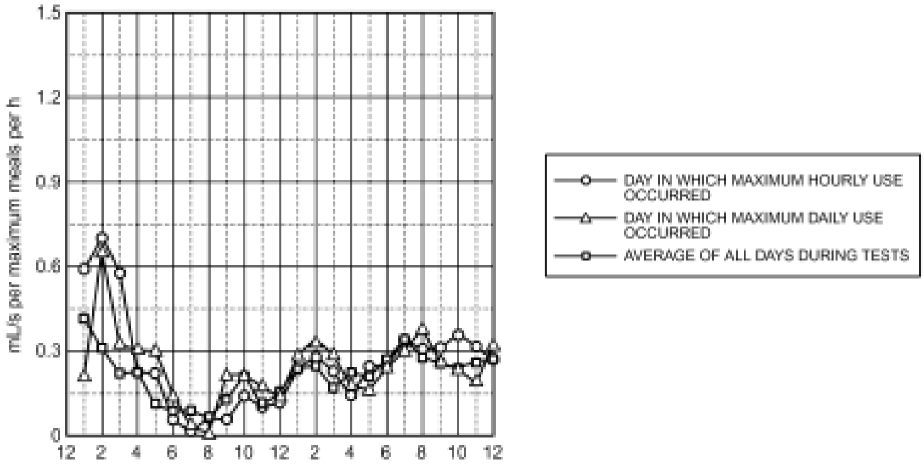

Figure 3-15: Hourly domestic hot water flow profile for Fast Food Restaurants [21]

The average daily water demand is based on the number of meals served at the Fast Food Restaurant. If less than two hundred meals are served per day the average domestic hot water consumption is 5 litres per meal. However, if more than two hundred meals are served per day the average domestic hot water consumption falls to 3 litres per meal.

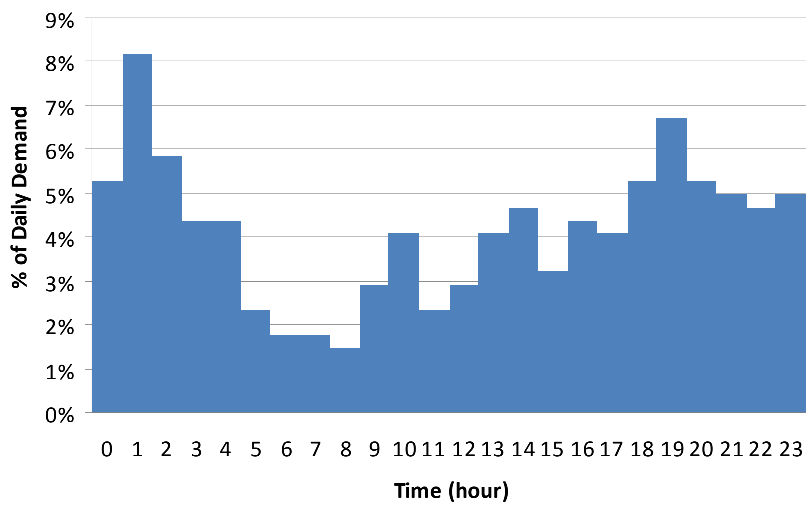

Figure 3-16: Daily domestic hot water load profile for Fast Food Restaurants

3.6.7 Primary Schools

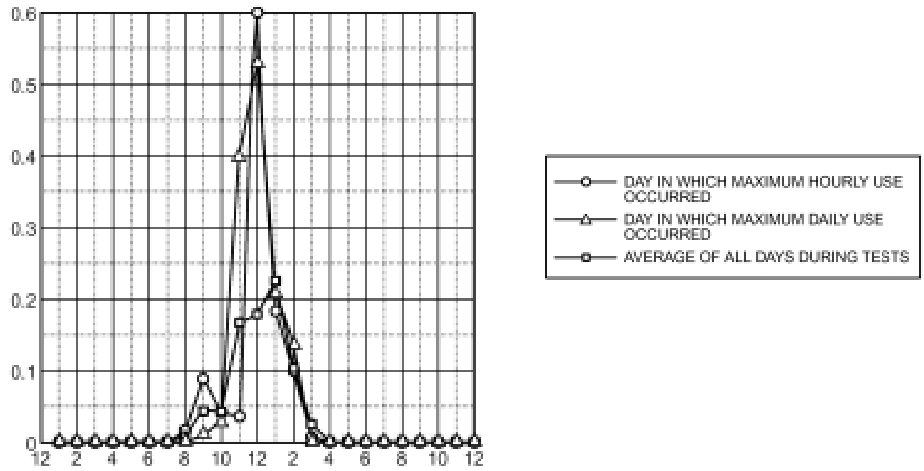

Figure 3-17: Hourly domestic hot water flow profile for Primary School [21]

Domestic hot water requirements in primarily schools are for toilet blocks, kitchen/tuck shop use, and general cleaning purposes. Additional hot water usage should also be considered for showers or other uncommon water applications.

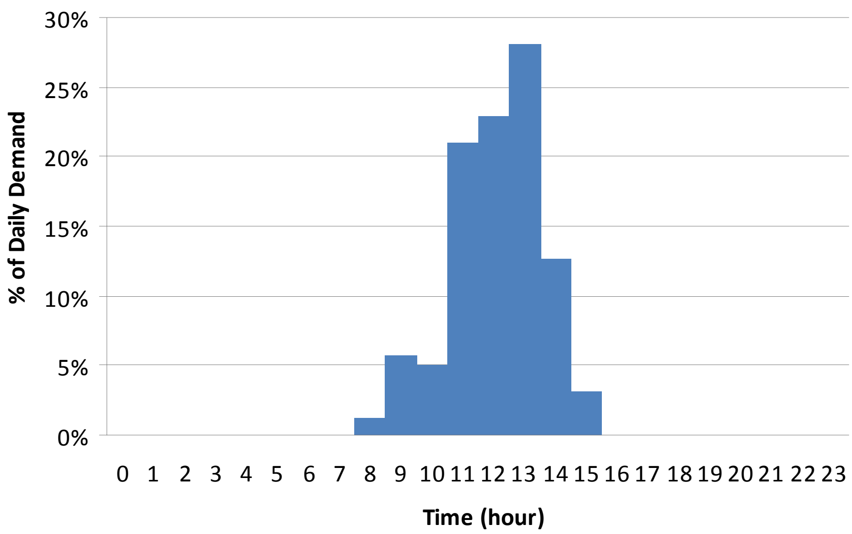

Figure 3-18: Daily domestic hot water load profile for Primary Schools

The average daily water demand is based on the number of students at the primary school, with an average domestic hot water consumption of 3 litres per student.

3.6.8 Secondary Schools

Domestic hot water requirements at Secondary Schools are primarily for showers, toilet blocks, dishwashers, kitchens and general cleaning. Intermediate schools have similar domestic hot water requirements to secondary schools.

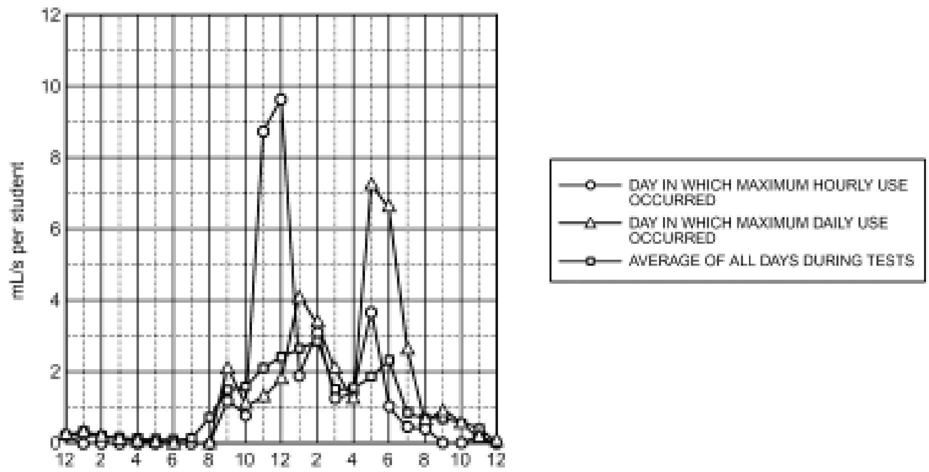

Figure 3-19: Hourly domestic hot water flow profile for Secondary School [21]

The average daily water demand is based on the number of students at the secondary school with an average domestic hot water consumption of 8 litres per student.

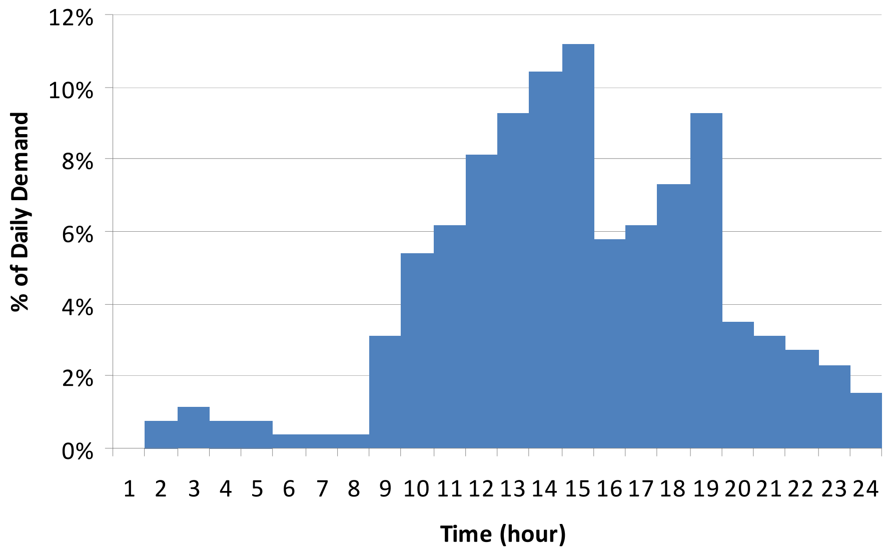

Figure 3-20: Daily domestic hot water load profile for Secondary Schools

4 Numerical Simulations

4.1 Introduction

This chapter details the TRNSYS simulations by outlining the design of experiments, details of equipment modelled in the simulations, cost of individual systems and the economic analysis. TRNSYS enables annual simulations of domestic solar hot water systems, which provides details to economically optimise the size of domestic solar hot water systems for each application.

4.2 Design of Experiments

The TRNSYS simulations are used to model domestic solar hot water systems. A number of simulations need to be completed in order to analyse the systems. A series of standard sized domestic solar hot water systems will need to be simulated for each commercial application. Each size of domestic solar hot water system will have an initial capital cost. The simulation results will enable an analysis of savings produced from each domestic solar hot water system which each commercial application. To provide a range of results each commercial application will need to be assessed across a range of sizes.

Previous studies indicate the number of panels and the size of the storage tank have a relationship of 40-50 litres per square meter of net solar panel area. The New Zealand standards recommend 50l/m² for safety, which shall be used as the relationship between the solar panel and storage tank.

There are standard sizes of tanks which are commonly available and should be utilised for economic reasons. The number of panels will be based on the size of the hot water cylinder. The standard domestic hot water cylinders that will be simulated are 300l, 500l, 800l and 1000l. There are also standard larger sizes made to order which include 2000l, 3000l and 5000l. A standard thirty tube evacuated tube Consol New Zealand Limited panel is 2.5m² in gross area. The manufacturers recommended the water flow rate through each panel should be 200l/hour. The maximum number of panels used in series is limited to two. The number of panels for a cylinder is based on a minimum of 50 litres of storage area per panel. Therefore, the standard size domestic hot water systems to be evaluated will be:

Table 4-1: Solar Domestic Hot Water System Sizes to be Evaluated

Storage Tank Size	Number of Panels	Net Panel Area	Water Flow-rate
300l	2	5m²	200l/hr
500l	4	10m²	400l/hr
800l	6	15m²	600l/hr
1000l	8	20m²	800l/hr
2000l	16	40m²	1600l/hr
3000l	24	60m²	2400l/hr
5000l	40	100m²	4000l/hr

The following eight commercial applications will be assessed and each have their own individual domestic hot water load profile:

- Motels and Hotels
- Apartments
- Retirement Homes
- Offices
- Restaurant and Cafes
- Fast Food Restaurants
- Primary Schools
- Secondary Schools

Each of the eight commercial applications will be assessed over a range of sizes to obtain a range of results. Further, an annualised life-cycle savings analysis will be completed with an inflated cost for the auxiliary energy over an expected system life of twenty years.

4.3 Equipment

Each solar domestic hot water system requires a range of equipment to be used in the simulation, which this section evaluates along with the specifications of the equipment.

4.3.1 Solar Hot Water Panels

The solar hot water panels modelled are the Consol New Zealand Limited thirty tube evacuator tube panel. The evacuator tubes have been assessed in accordance with the Australian and New Zealand Standards by the Applied Research Services Limited facility in Nelson. The full report can be viewed in Appendix B.

Table 4-2: Solar Hot Water Panel Specification

Collector type:	Evacuator tube with heat pipes
Model:	D-58-1800-30
Gross length:	1.923m
Gross width:	2.459m
Gross height:	0.128m
Gross area:	4.725m²
Net (absorber) area:	2.429m²
Empty weight:	96kg
Fluid capacity:	2.0l
Flow range:	170 – 205l/h
Mounted angle:	45° true North

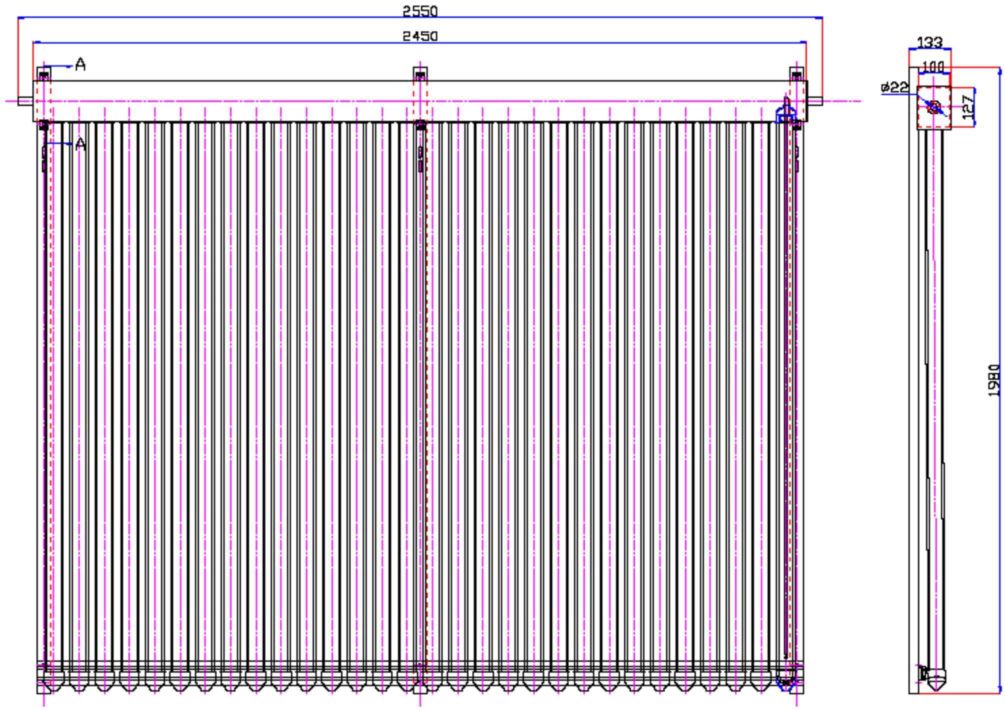

Figure 4-1: D58-1800-30 solar hot water panel

4.3.2 Domestic Hot Water Cylinders

The hot water cylinders are commercially available cylinders for 300l – 1000l. Above 1000l will be standard cylinders, that are locally made to order. The heat loss coefficient used is based on the maximum requirements by the New Zealand Standards.

Table 4-3: Hot Water Cylinder Specifications

Volume	Diameter	Height	Heat loss Coefficient (kJ/h.m².K)
300l	0.58m	1.83m	3.36
500l	0.75m	1.86m	3.53
800l	1.06m	1.75m	3.60
1000l	1.06m	2.09m	3.80
2000l	1.35m	2.09m	5.28
3000l	1.70m	2.09m	5.78
5000l	2.00m	2.09m	7.64

4.3.3 Pumps

Pumps are commercially available and Wilo pumps are commonly used in solar hot water systems.

Table 4-4: Pump Specifications

System Volume	Pump Flow-rate	Pump Power
300l	200l/hr	28W
500l	400l/hr	48W
800l	600l/hr	61W
1000l	800l/h	84W
2000l	1600l/h	92W
3000l	2400l/h	132W
5000l	4000l/h	195W

4.3.4 Miscellaneous Items

A number of miscellaneous items are required to make up the balance of a working solar domestic hot water system. These include:

- Pipework and associated valves to and from the storage tank.
- Pipework and associated valves to and from the solar hot water panels from the storage tank.
- Safety valve set for the storage tank.
- Controls and wiring to the system.
- Air relief valve at a local high point in the system.

Additional frames and mounting may be required depending on the type and pitch of the roof, however, these have been excluded from the initial cost.

4.4 System Cost

Each solar domestic hot water system has been priced based on detailed scheduled rates using Rawlinsons New Zealand Construction Handbook 2010 [35]. Ten metres of pipe was allowed to and from the panels from the storage tank (in accordance with the Australian and New Zealand Standard) with an additional five metres per panel. Ten metres of pipe was allowed to install the water storage tank. All pipework is copper. For 32mm or smaller the pipework is modelled with 13mm Armaflex, while for 40mm and above the pipework is modelled with aluminium foil covered fibreglass. A full detailed price for each individual system is outlined in Appendix C.

Table 4-5: Domestic Solar Hot Water System Capital Cost

System Volume	System Cost
300l	$9,651.00
500l	$15,367.00
800l	$22,757.00
1000l	$28,382.00
2000l	$58,300.00
3000l	$85,322.00
5000l	$144,771.00

4.5 *Cost Analysis*

An annualised life-cycle cost analysis will be completed over an expected system life of twenty years.

$$LCC = (ES*CE) – CC - AER \tag{4-1}$$

where ES = Energy Saved (by solar)

CE = Cost of Energy

CC = Capital Cost

AER = Additional Energy Required

Each commercial application will have a base case cost, to analyse the hot water heating without solar hot water. The base case is a reference for each commercial application where only auxiliary energy will be used to heat the water. The energy saved from adding solar panels to the domestic hot water system is associated with the amount of auxiliary energy no longer required. The additional pumping energy will also be taken into account. The cost of energy is based on having an electric based domestic hot water system. The cost of electricity in the commercial market is dependent on the premises and is generally between 14c/kWh and 28c/kWh. For the cost analysis a conservative base case of 19c/kWh will be used with inflation of 3% per year.

5 Experimental Results and Discussion

5.1 Introduction

This section presents the results obtained from the TRNSYS simulations, which are used to economically optimise the size of domestic solar hot water system for each commercial application. A simulation was created for each eight commercial applications. Each commercial application has its own individual domestic hot water demand profile which makes each commercial application unique. A variety of sizes for each commercial application was used, with an array of solar hot water storage sizes in order to obtain a range of results.

The eight commercial applications simulated are:

- Hotels and motels
- Apartments (2-3 bedroom apartments)
- Retirement homes
- Office buildings
- Café and restaurants
- Fast food/take away restaurants

- Primary schools
- Secondary schools

The TRNSYS simulation program was used to complete an annual simulation of each system over a range of sizes for the eight commercial applications. Each individual simulation provided the annual energy savings of the solar system for each circumstance. The annual energy saving from each of the simulations is economically evaluated over the expected life of the system of twenty years. This provides the economically optimal size system for each of the commercial applications.

5.2 Experimental Results

Each of the eight commercial applications has a table of the simulation results for the net financial position after twenty years. The net financial position is graphed using a second order polynomial used fit the data. From the second order polynomial equation, an economically optimal solar hot water storage tank size is calculated for a number of sizes for each commercial application. The range of sizes for the commercial applications is adjusted economically for the optimal solar hot water storage tank size. This data is then graphed, and a linear relationship between the size of the solar hot water storage tank and size of the commercial application is identified. The raw data from the simulations are shown in the graph to identify how the simulations relate to the linear relationship.

5.2.1 Motel and Hotels

Table 5-1: Motel and Hotel Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
	NUMBER OF BEDS							
SYSTEM (l)	**10 Beds**	**15 Beds**	**20 Beds**	**30 Beds**	**35 Beds**	**40 Beds**	**50 Beds**	**60 Beds**
300	$6,972.39	$7,527.46	$7,600.49	$7,658.92	$7,804.99	$8,097.13	$8,243.20	$8,535.34
500	$13,526.30	$17,192.66	$18,375.83	$18,741.01	$18,887.08	$19,033.15	$19,179.22	$19,763.50
800	$16,400.08	$21,658.61	$25,690.15	$27,851.99	$29,078.98	$29,809.33	$30,101.47	$30,101.47
1000	$18,644.03	$26,035.19	$31,133.05	$34,667.95	$37,603.96	$39,648.95	$41,547.86	$42,132.14
2000	$1,619.66	$20,886.34	$37,392.29	$45,440.76	$50,275.69	$54,248.80	$62,720.88	$69,878.33
3000	-$19,831.95	$5,759.58	$25,917.28	$39,954.64	$53,057.15	$64,552.89	$76,516.05	$84,842.06
5000	-$75,776.72	-$44,644.75	-$16,935.20	$2,769.69	$20,517.23	$36,292.83	$64,645.08	$91,478.20

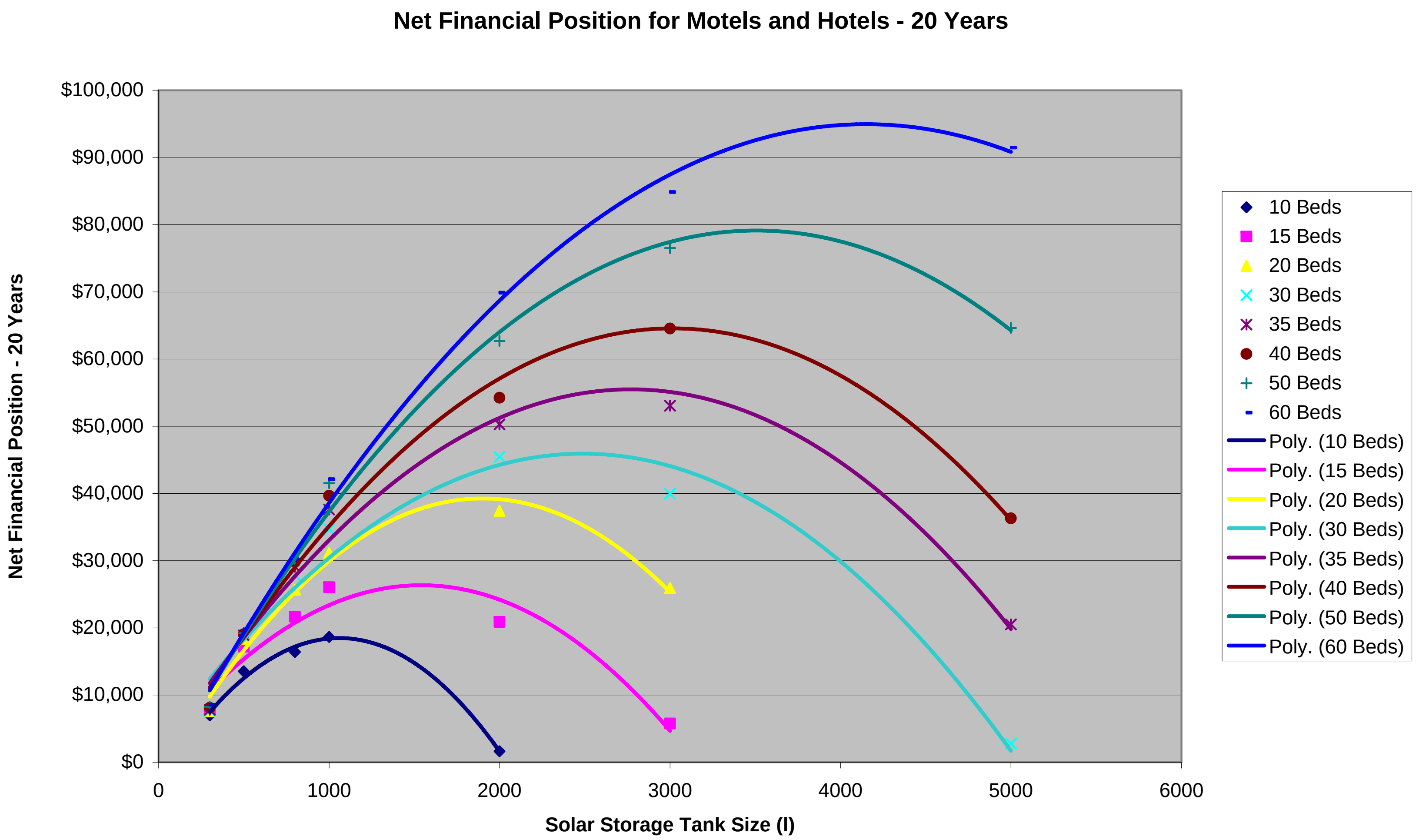

Figure 5-1: Motel and Hotel net financial position complete with second order polynomial trend-lines

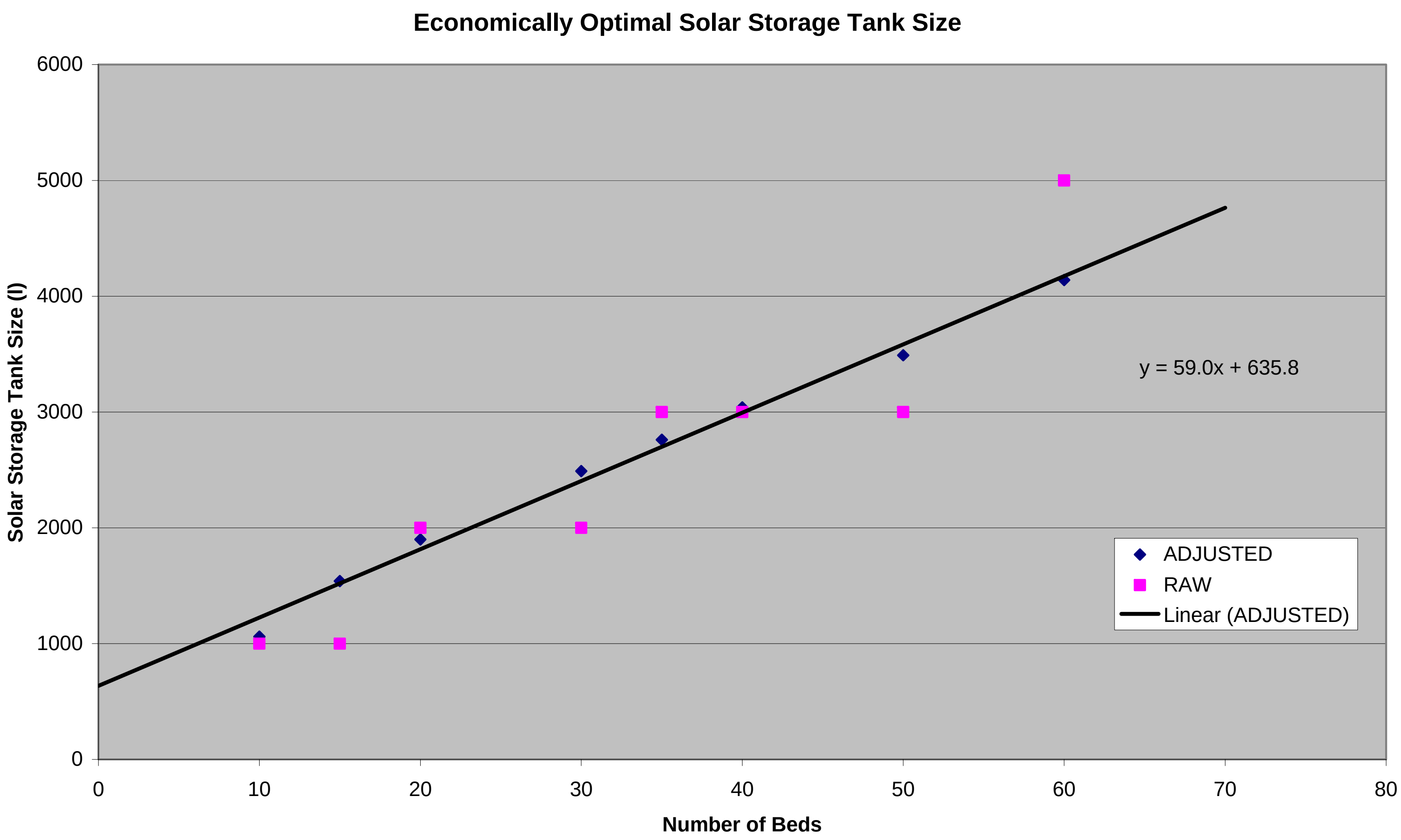

Figure 5-2: Motels and Hotels economically optimal solar storage tank size

5.2.2 Apartments

Table 5-2: Apartment Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
	NUMBER OF APARTMENTS							
SYSTEM (l)	4 Apartments	6 Apartments	8 Apartments	10 Apartments	12 Apartments	14 Apartments	16 Apartments	20 Apartments
300	$6,417.91	$6,111.16	$5,906.66	$6,052.73	$6,490.94	$6,929.15	$7,367.36	$8,389.86
500	$15,571.87	$16,623.57	$16,287.61	$15,966.26	$15,528.05	$15,528.05	$15,674.12	$16,404.47
800	$19,850.99	$25,270.20	$27,037.65	$27,037.65	$26,453.37	$25,869.09	$25,284.80	$24,700.52
1000	$20,711.37	$31,535.18	$36,004.93	$38,049.91	$38,488.13	$37,903.84	$37,173.49	$36,151.00
2000	$5,008.64	$25,385.45	$41,686.90	$54,979.30	$63,495.20	$69,002.06	$72,361.67	$76,597.71
3000	-$16,060.85	$10,699.24	$32,054.72	$50,167.44	$65,826.18	$80,330.97	$90,512.07	$104,096.61
5000	-$71,352.83	-$38,628.69	-$9,735.98	$15,826.33	$37,955.99	$57,879.98	$75,364.60	$107,660.75

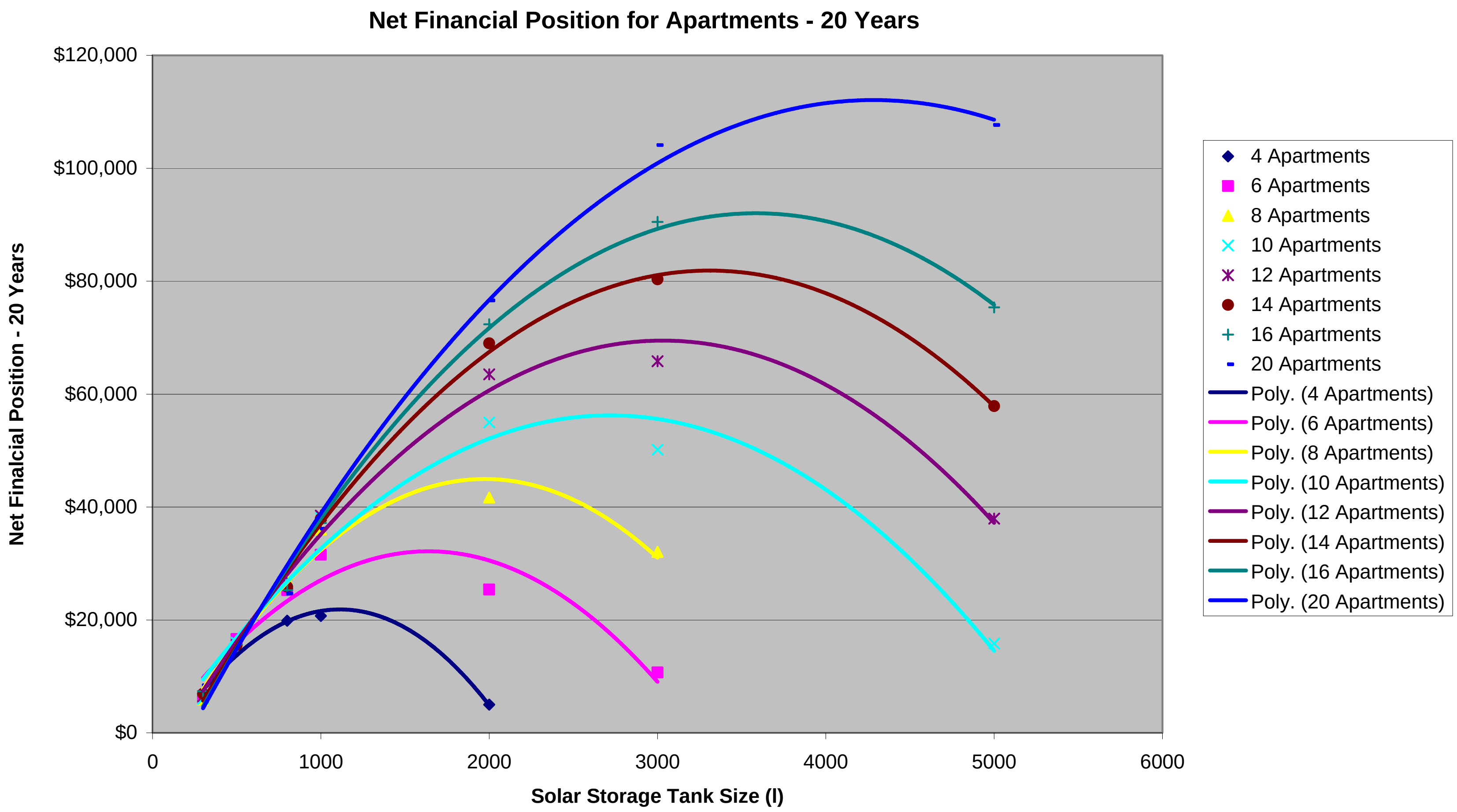

Figure 5-3: Apartment net financial position complete with second order polynomial trend-lines

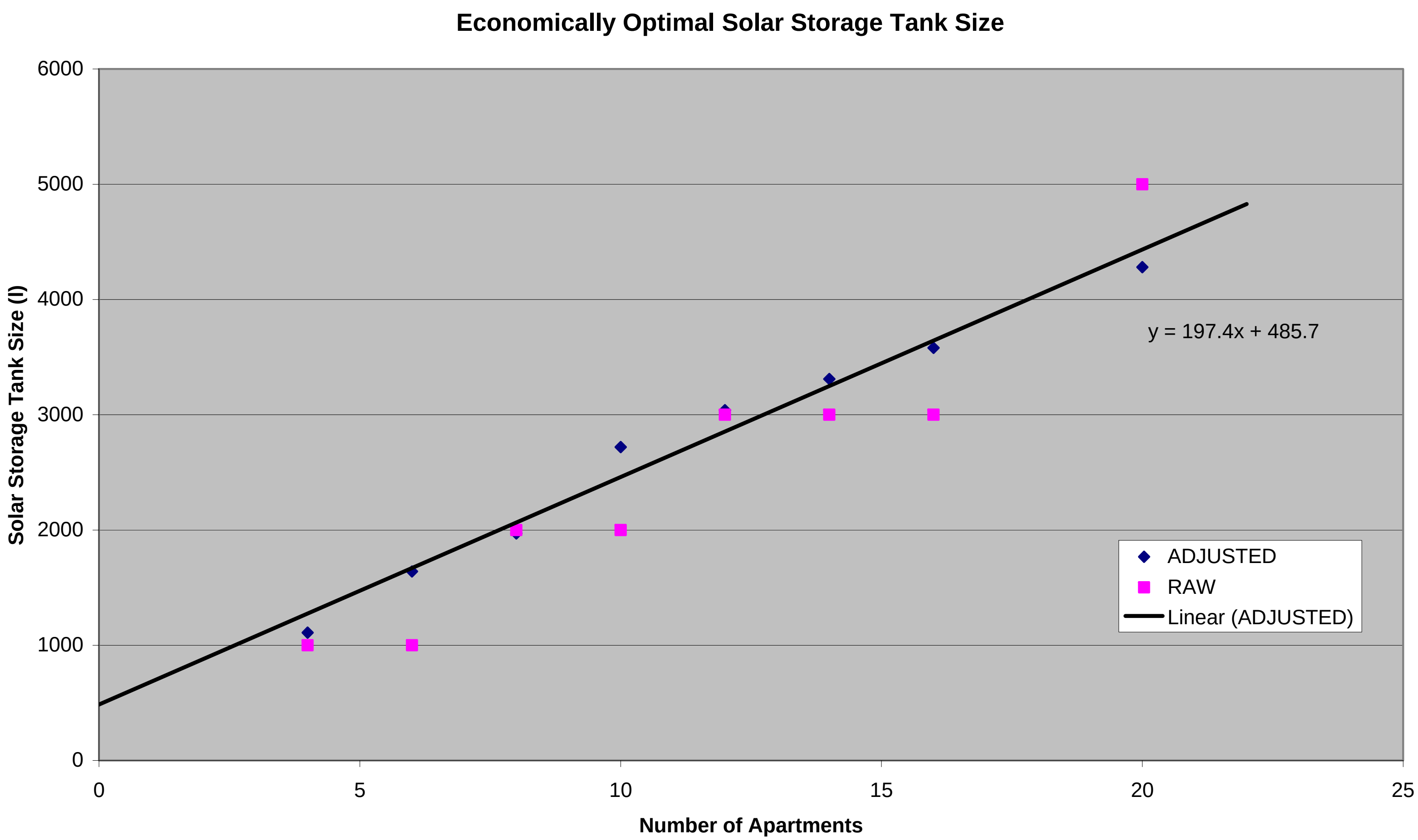

Figure 5-4: Apartments economically optimal solar storage tank size

5.2.3 Retirement Homes

Table 5-3: Retirement Home Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
	NUMBER OF BEDS							
SYSTEM (l)	**10 Beds**	**20 Beds**	**25 Beds**	**30 Beds**	**40 Beds**	**45 Beds**	**50 Beds**	**60 Beds**
300	$5,858.46	$7,625.91	$8,093.33	$8,385.47	$9,407.97	$9,700.11	$9,992.25	$10,576.53
500	$12,305.30	$17,315.51	$18,294.18	$18,732.39	$19,754.88	$20,193.09	$20,777.38	$21,799.87
800	$14,624.59	$23,520.28	$25,755.15	$27,172.03	$29,217.02	$29,655.23	$29,947.37	$30,823.79
1000	$14,335.98	$29,644.15	$32,989.16	$35,253.25	$38,758.94	$39,781.43	$40,657.85	$41,680.35
2000	-$2,882.96	$29,676.12	$41,785.35	$50,447.32	$59,781.22	$63,140.84	$66,354.38	$71,028.64
3000	-$24,952.44	$18,674.39	$34,303.91	$47,742.38	$71,522.64	$78,972.22	$84,815.04	$92,994.98
5000	-$81,125.96	-$26,260.48	-$2,962.26	$17,224.66	$50,499.48	$63,733.46	$77,697.78	$102,967.95

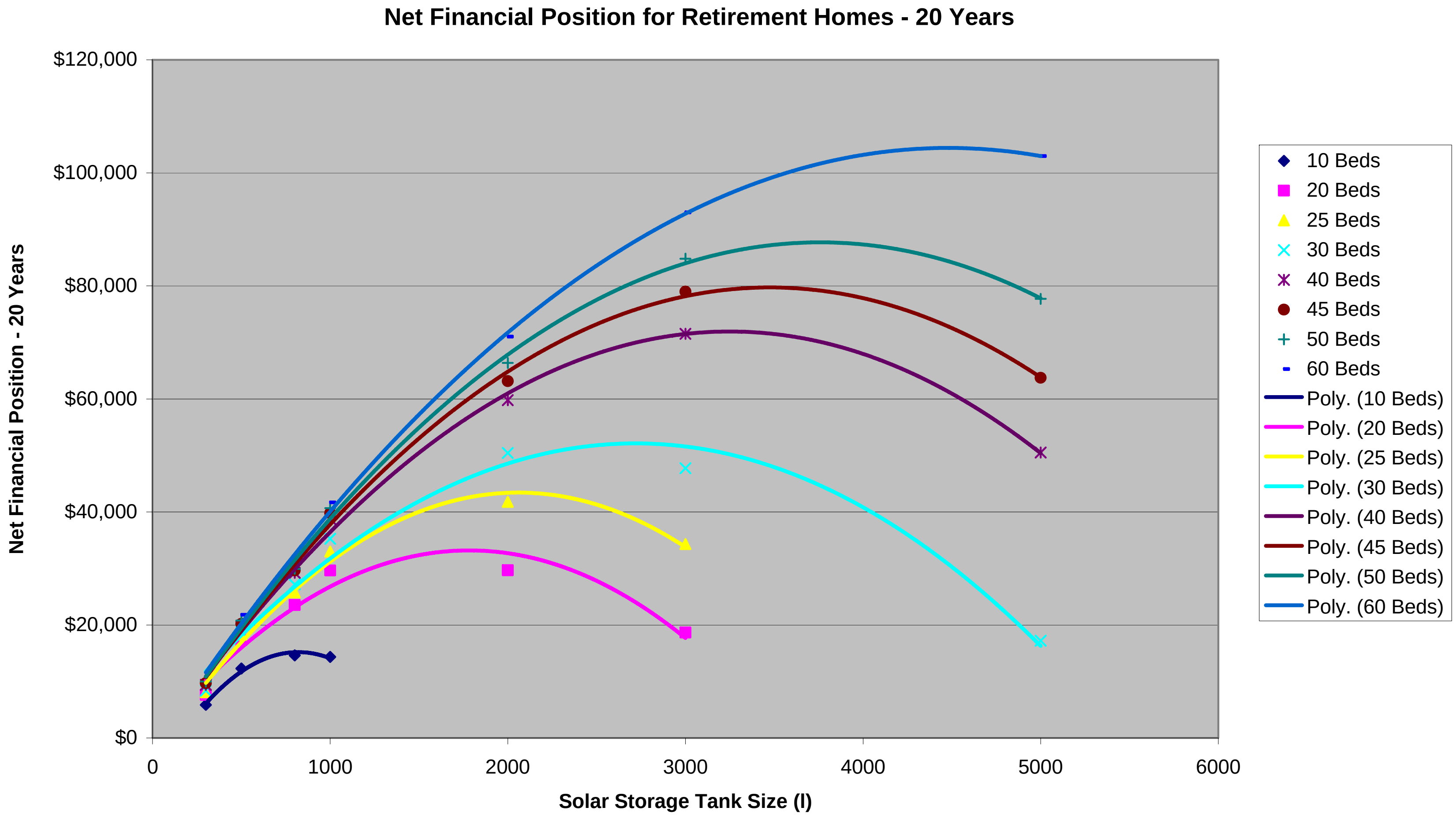

Figure 5-5: Retirement Home net financial position complete with second order polynomial trend-lines

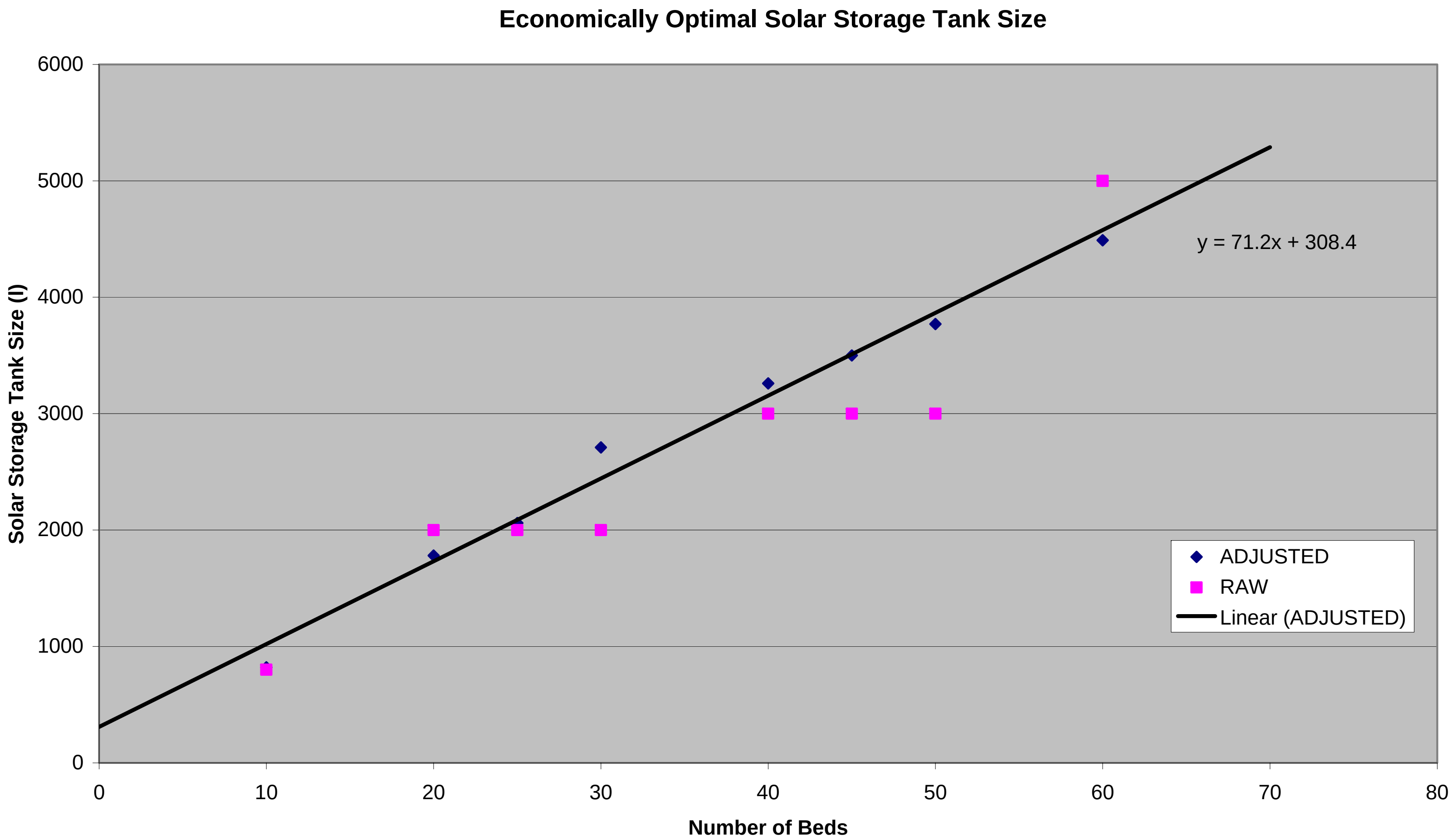

Figure 5-6: Retirement Home economically optimal solar storage tank size

5.2.4 Offices

Table 5-4: Office Building Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
	NUMBER OF PEOPLE							
SYSTEM (l)	**100 Persons**	**200 Persons**	**250 Persons**	**300 Persons**	**350 Persons**	**400 Persons**	**500 Persons**	**600 Persons**
300	$2,835.53	$5,859.19	$7,509.78	$8,824.41	$9,554.77	$10,431.19	$11,307.61	$12,037.96
500	$8,466.71	$9,854.38	$11,373.51	$13,184.79	$15,083.70	$17,274.75	$20,780.44	$23,117.57
800	$9,718.38	$14,991.52	$15,400.52	$16,218.51	$17,533.14	$19,285.99	$22,791.68	$27,173.79
1000	$9,350.89	$21,197.20	$22,307.33	$22,146.65	$22,701.72	$23,432.07	$26,207.41	$29,420.96
2000	-$9,798.66	$19,108.66	$28,851.55	$35,673.04	$40,522.57	$42,845.09	$45,036.15	$44,451.87
3000	-$32,657.21	$6,146.37	$20,519.69	$31,957.00	$42,196.53	$50,055.12	$61,317.14	$67,598.16
5000	-$89,363.60	-$41,337.13	-$21,106.39	-$2,599.28	$13,541.50	$27,535.04	$51,432.14	$71,458.39

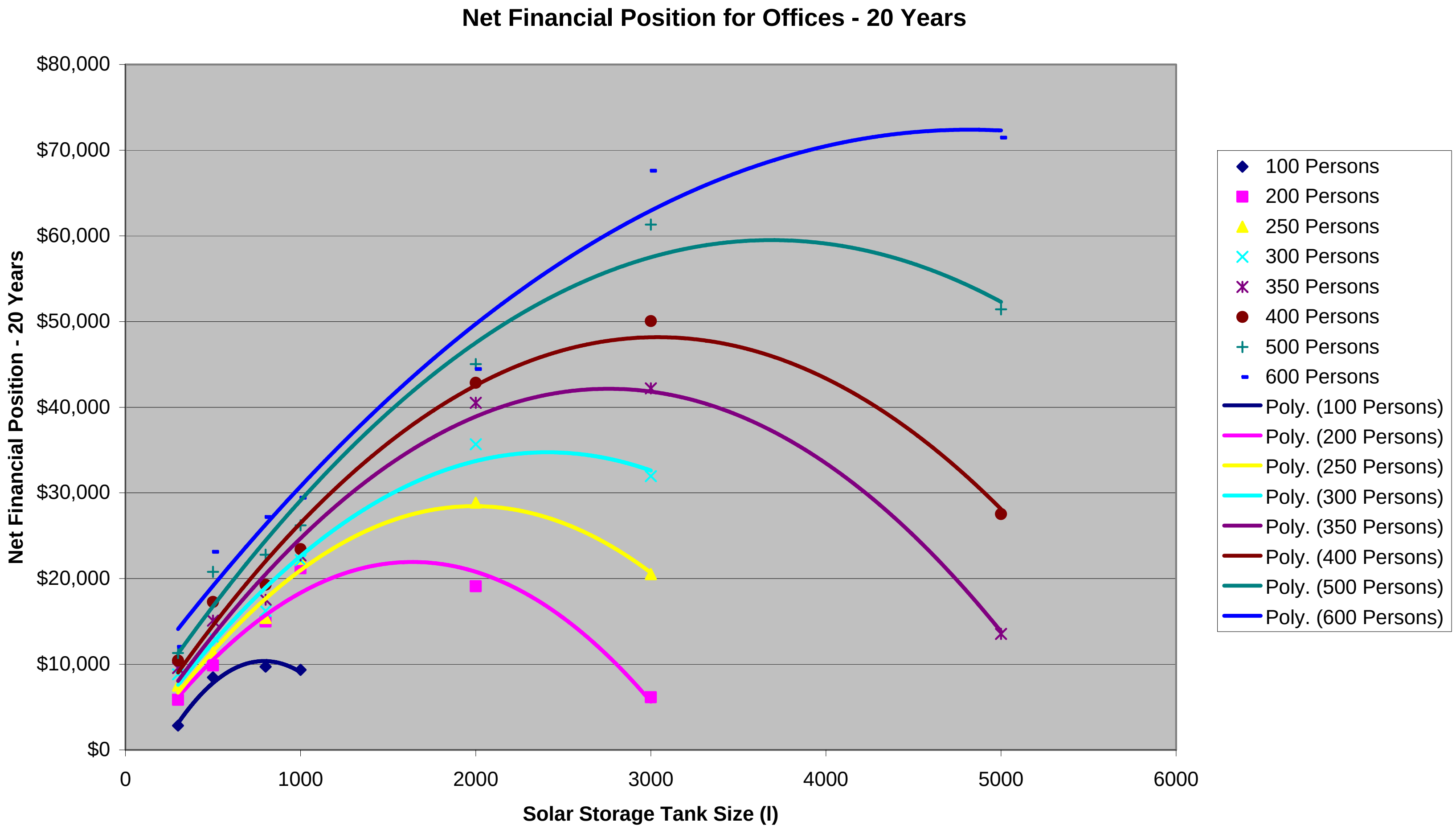

Figure 5-7: Office net financial position complete with second order polynomial trend-lines

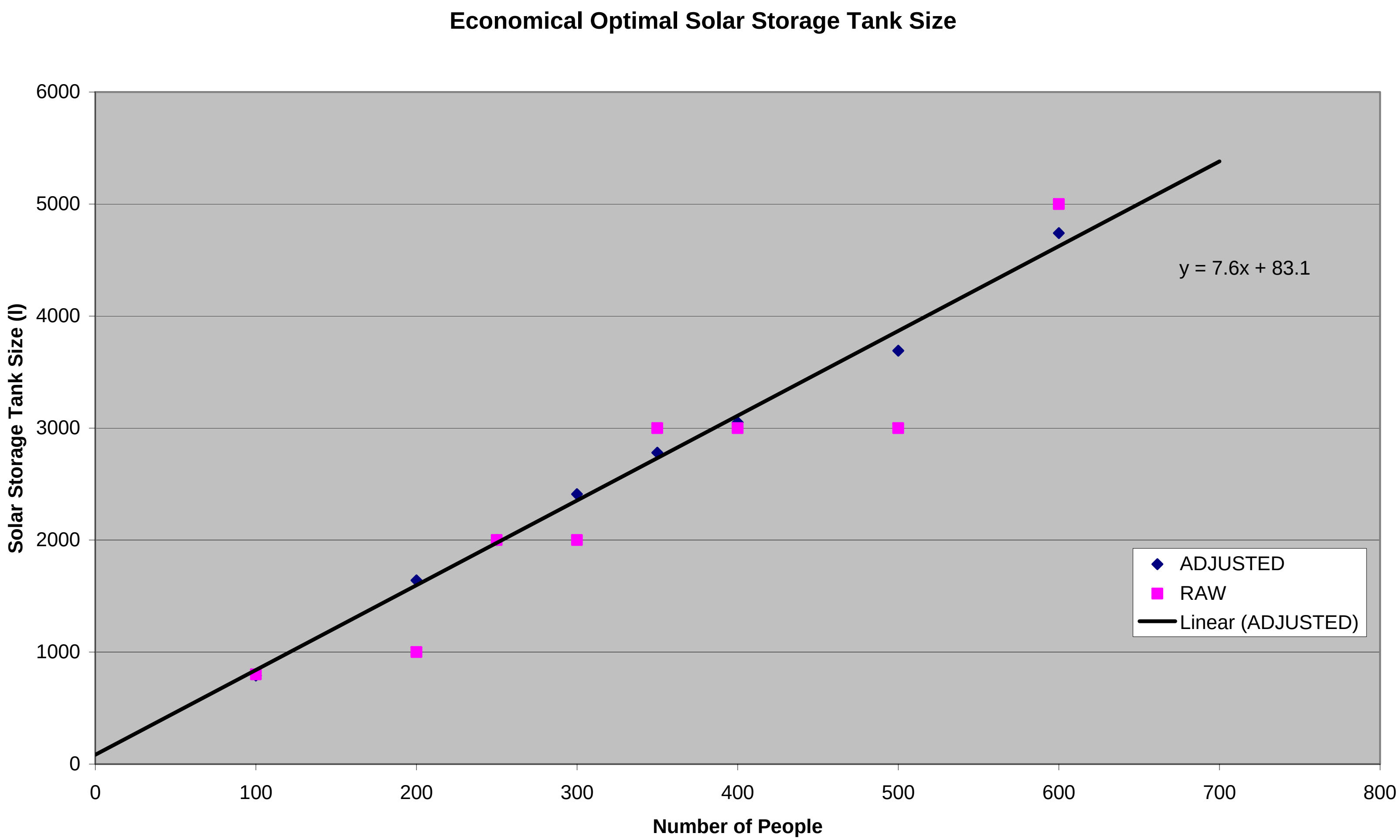

Figure 5-8: Office economically optimal solar storage tank size

5.2.5 Cafés and Restaurants

Table 5-5: Cafe and Restaurant Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
				NUMBER OF MEALS				
SYSTEM (l)	**40 Meals**	**80 Meals**	**100 Meals**	**125 Meals**	**150 Meals**	**175 Meals**	**200 Meals**	**250 Meals**
300	$4,327.64	$1,128.70	$2,837.72	$5,759.13	$7,365.90	$8,242.32	$8,680.54	$9,410.89
500	$13,234.89	$7,085.33	$4,251.56	$3,258.28	$3,842.56	$5,741.48	$9,539.31	$16,988.90
800	$14,599.18	$22,209.44	$19,916.14	$14,044.11	$10,100.21	$7,763.08	$7,178.80	$10,976.63
1000	$13,650.18	$32,653.93	$32,493.25	$29,002.17	$22,282.94	$16,440.12	$12,788.36	$10,013.03
2000	-$7,423.55	$27,440.52	$40,250.88	$52,798.33	$60,686.12	$64,761.49	$65,199.70	$58,480.46
3000	-$31,092.80	$11,857.72	$29,313.13	$47,937.10	$63,405.95	$76,785.99	$86,426.63	$99,134.75
5000	-$88,463.37	-$37,645.49	-$15,296.73	$10,031.86	$33,096.37	$53,297.90	$71,907.26	$104,364.09

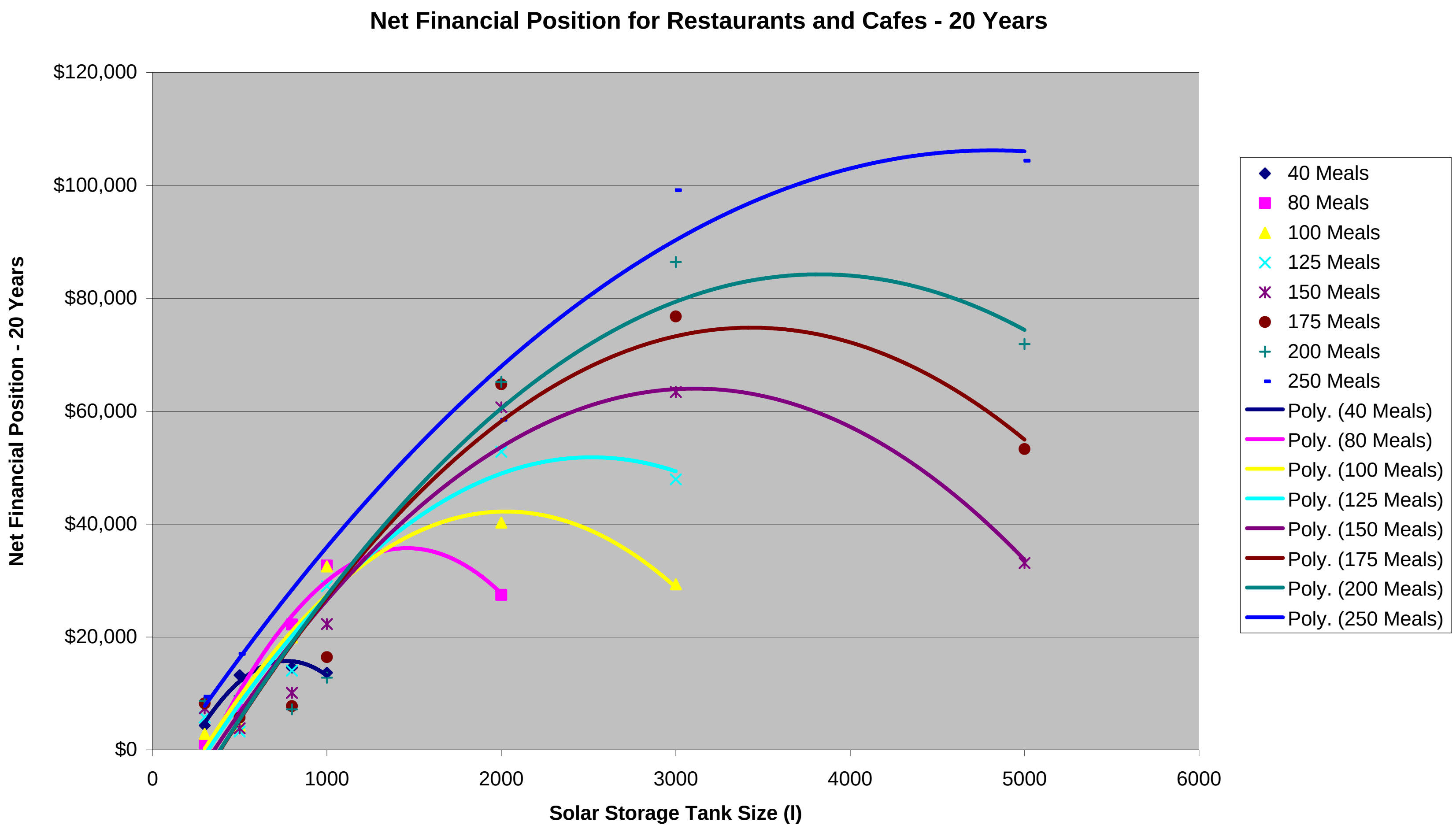

Figure 5-9: Cafe and Restaurant net financial position complete with second order polynomial trend-lines

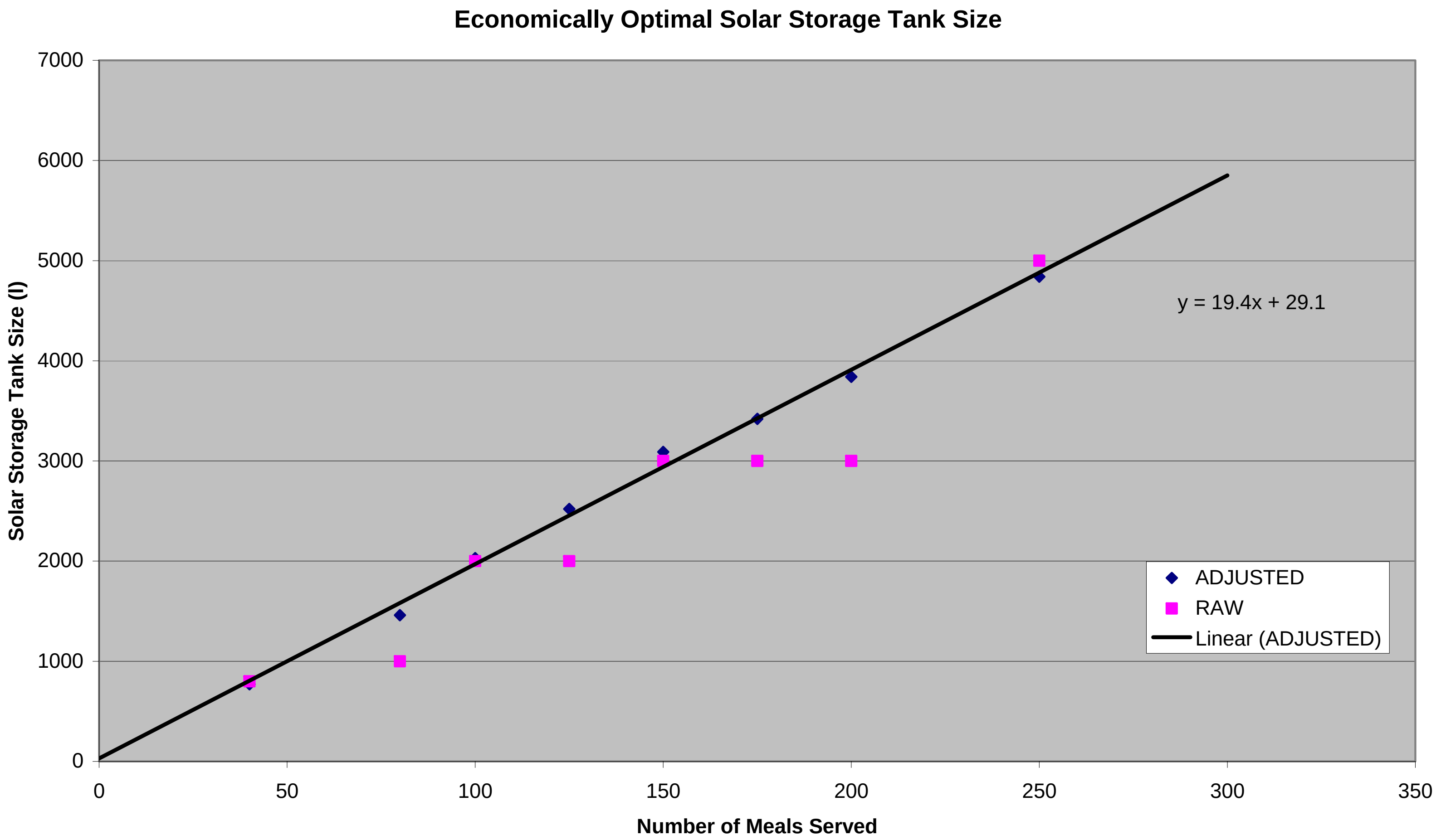

Figure 5-10: Cafe and Restaurant economically optimal solar storage tank size

5.2.6 Fast Food Restaurants

Table 5-6: Fast Food Restaurant Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
	NUMBER OF MEALS							
SYSTEM (l)	**250 Meals**	**300 Meals**	**400 Meals**	**500 Meals**	**600 Meals**	**700 Meals**	**800 Meals**	**1000 Meals**
300	$4,700.70	$4,335.53	$3,502.93	$3,137.75	$3,283.82	$3,575.96	$4,014.17	$4,890.59
500	$14,511.83	$14,409.59	$13,445.52	$12,174.71	$11,152.22	$10,275.79	$9,983.65	$10,129.72
800	$20,195.57	$22,693.37	$24,270.93	$23,861.93	$22,518.09	$21,203.45	$19,888.82	$17,259.55
1000	$20,991.53	$26,746.70	$32,647.94	$34,430.00	$34,240.11	$33,538.97	$32,078.27	$29,302.93
2000	$3,417.20	$12,897.17	$28,468.27	$42,213.49	$53,694.61	$61,509.38	$65,789.24	$69,455.60
3000	-$18,598.67	-$7,124.85	$13,237.36	$30,780.40	$46,015.54	$60,169.76	$72,498.09	$92,159.16
5000	-$74,710.99	-$61,364.54	-$36,811.58	-$14,112.25	$6,951.09	$26,393.06	$44,052.96	$74,654.70

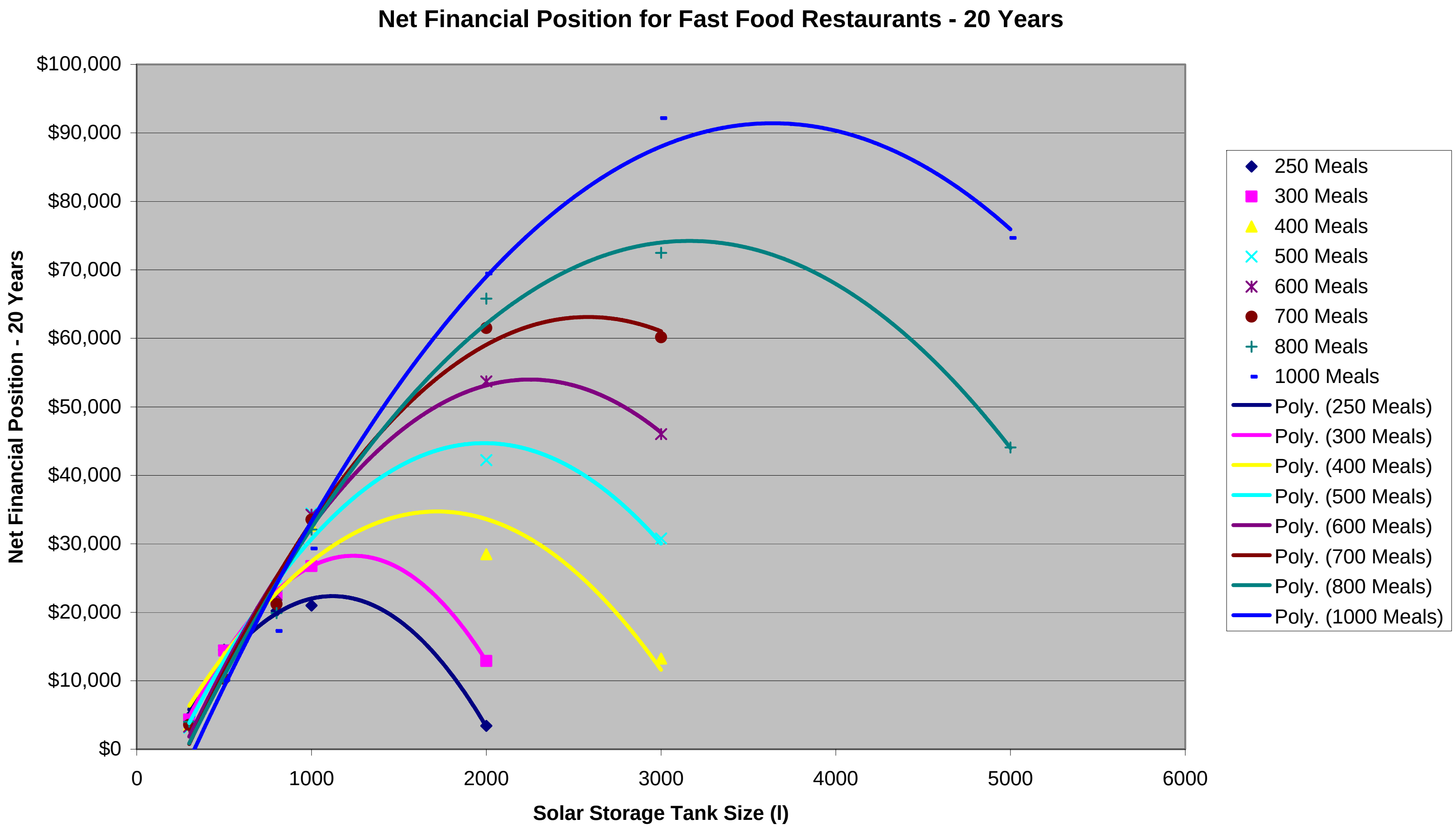

Figure 5-11: Fast Food Restaurant net financial position complete with second order polynomial trend-lines

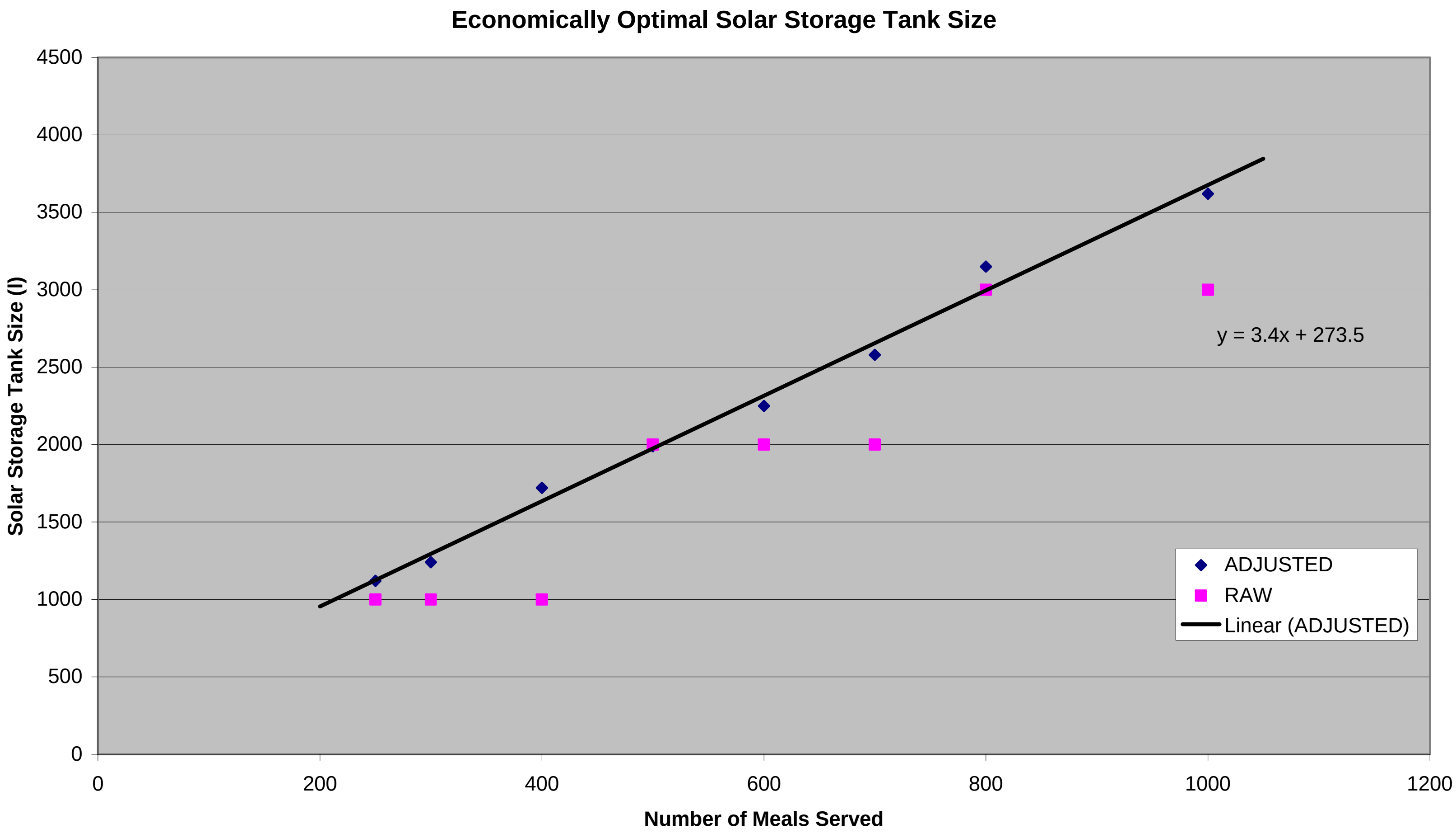

Figure 5-12: Fast Food Restaurant economically optimal solar storage tank size

5.2.7 Primary Schools

Table 5-7: Primary School Net Financial Position Simulation Data

	NET FINANCIAL POSITION - 20 YEARS							
	NUMBER OF STUDENTS							
SYSTEM (I)	**100 Students**	**200 Students**	**300 Students**	**400 Students**	**500 Students**	**700 Students**	**800 Students**	**1000 Students**
300	$1,178.95	$4,480.14	$6,510.51	$7,971.22	$8,891.46	$9,709.46	$9,855.53	$10,439.81
500	$1,759.02	$7,606.21	$11,433.26	$14,208.59	$16,385.04	$20,212.08	$21,234.58	$22,695.28
800	-$2,021.00	$8,016.95	$12,997.95	$16,971.07	$20,432.93	$25,151.00	$27,342.06	$30,993.82
1000	-$5,822.46	$7,950.51	$14,655.14	$19,051.86	$23,623.86	$29,306.00	$31,643.12	$36,463.44
2000	-$32,576.28	-$11,472.04	$4,668.73	$16,281.33	$23,730.91	$34,540.12	$38,513.23	$47,569.59
3000	-$58,503.92	-$34,286.92	-$14,139.44	$2,497.97	$17,265.68	$34,867.16	$42,170.68	$53,184.38
5000	-$117,454.82	-$90,712.27	-$66,537.62	-$44,860.79	-$25,491.86	$7,286.33	$22,200.11	$44,534.26

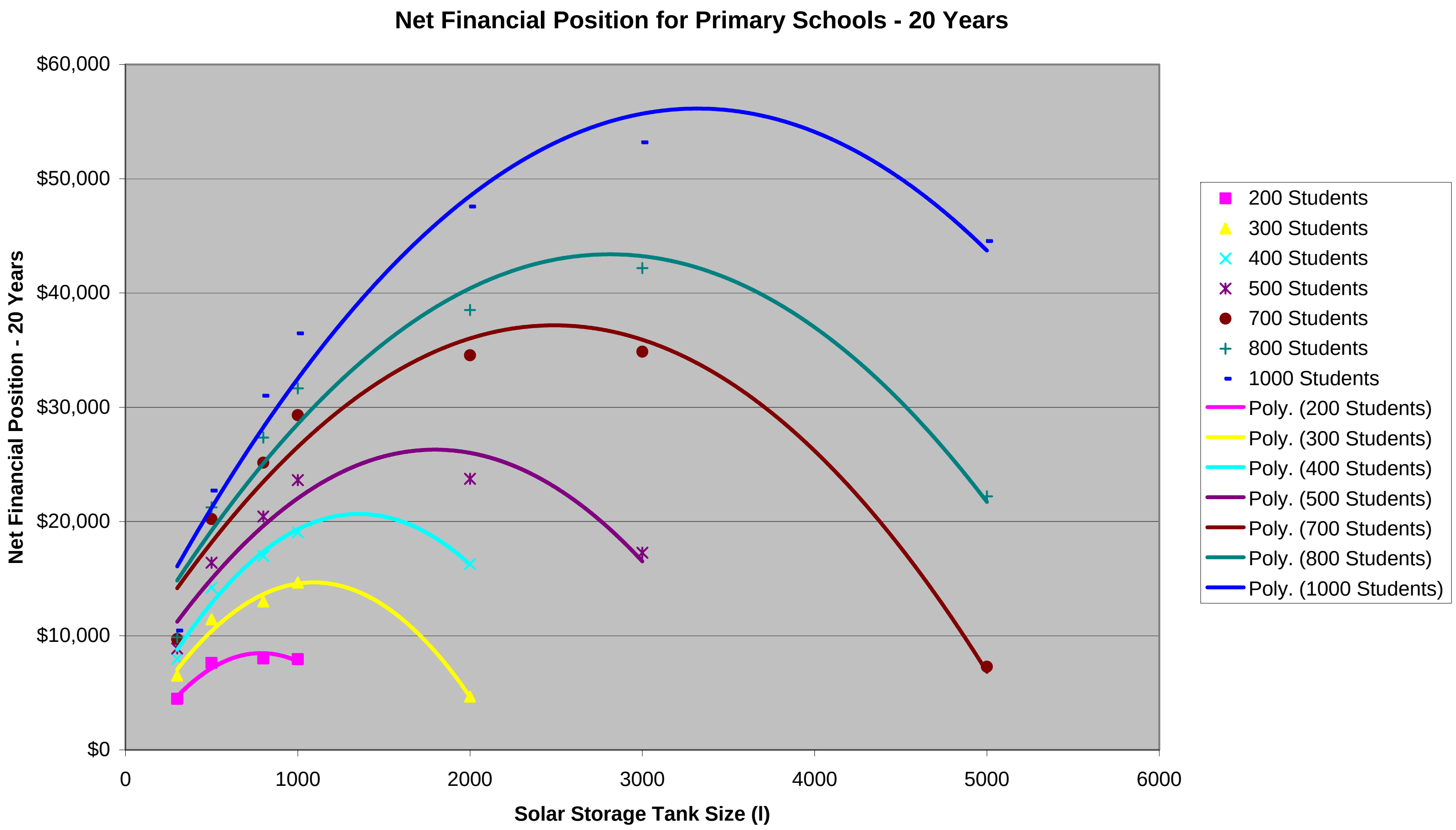

Figure 5-13: Primary School net financial position complete with second order polynomial trend-lines

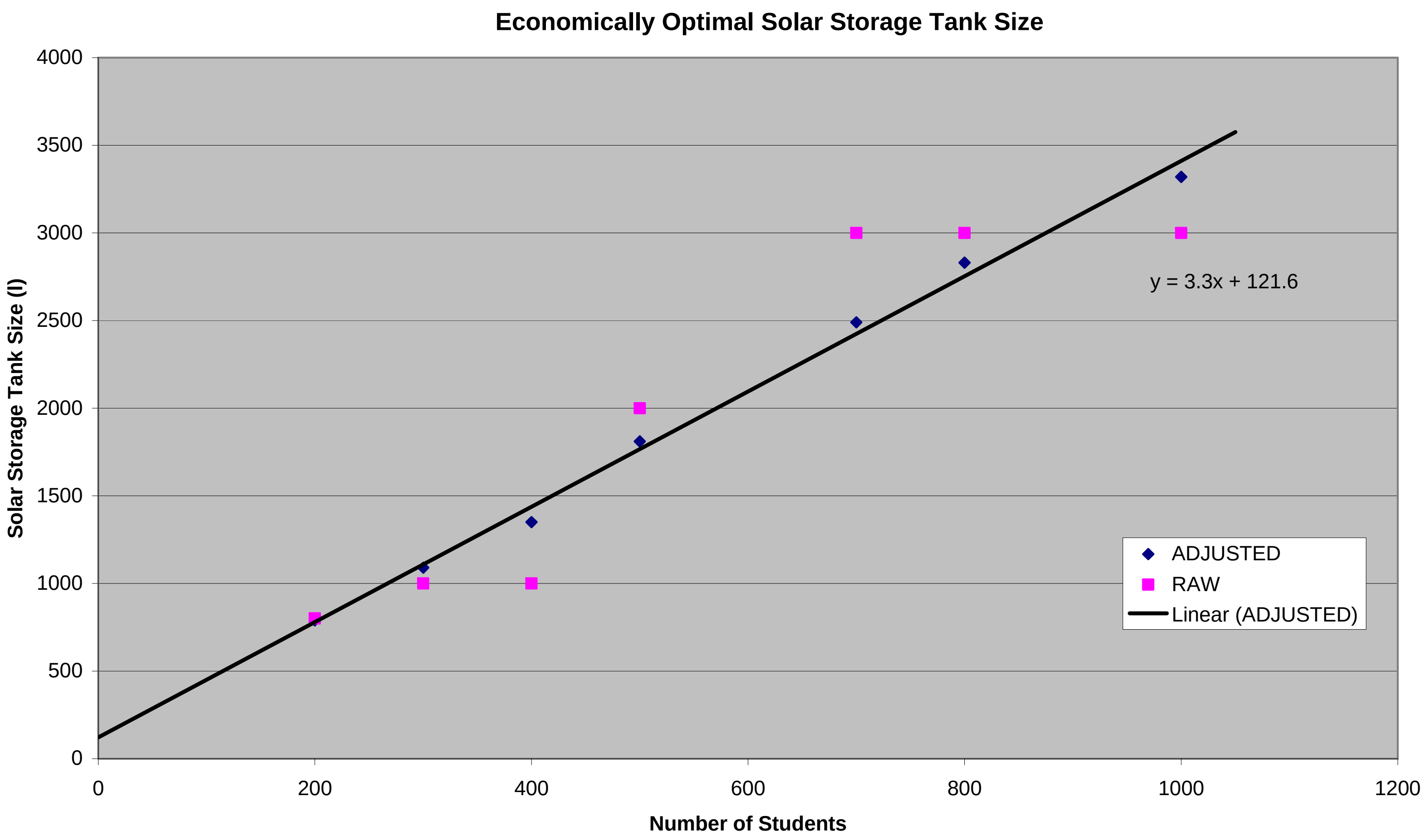

Figure 5-14: Primary School economically optimal solar storage tank size

5.2.8 *Secondary Schools*

Table 5-8: Secondary School Net Financial Position Simulation Data

NET FINANCIAL POSITION - 20 YEARS								
	NUMBER OF STUDENTS							
SYSTEM (l)	**100 Students**	**150 Students**	**200 Students**	**250 Students**	**300 Students**	**350 Students**	**400 Students**	**500 Students**
300	$5,084.87	$5,669.15	$6,779.28	$7,947.85	$8,824.27	$9,700.69	$10,431.04	$11,453.54
500	$13,360.36	$13,959.25	$14,090.71	$14,791.85	$15,960.41	$17,275.05	$18,735.75	$21,218.95
800	$17,081.35	$21,463.46	$22,354.49	$22,500.56	$22,500.56	$22,792.70	$23,815.19	$26,298.39
1000	$18,372.19	$27,589.23	$30,978.07	$32,190.45	$32,190.45	$31,898.31	$31,898.31	$33,066.87
2000	$3,539.76	$22,149.12	$37,179.76	$48,062.00	$55,555.40	$60,229.65	$62,420.71	$64,757.84
3000	-$17,118.84	$7,114.23	$28,469.72	$44,186.89	$58,852.35	$69,632.34	$79,711.19	$91,396.82
5000	-$71,822.01	-$40,118.90	-$12,336.33	$12,305.74	$33,515.16	$50,824.49	$66,979.87	$96,427.65

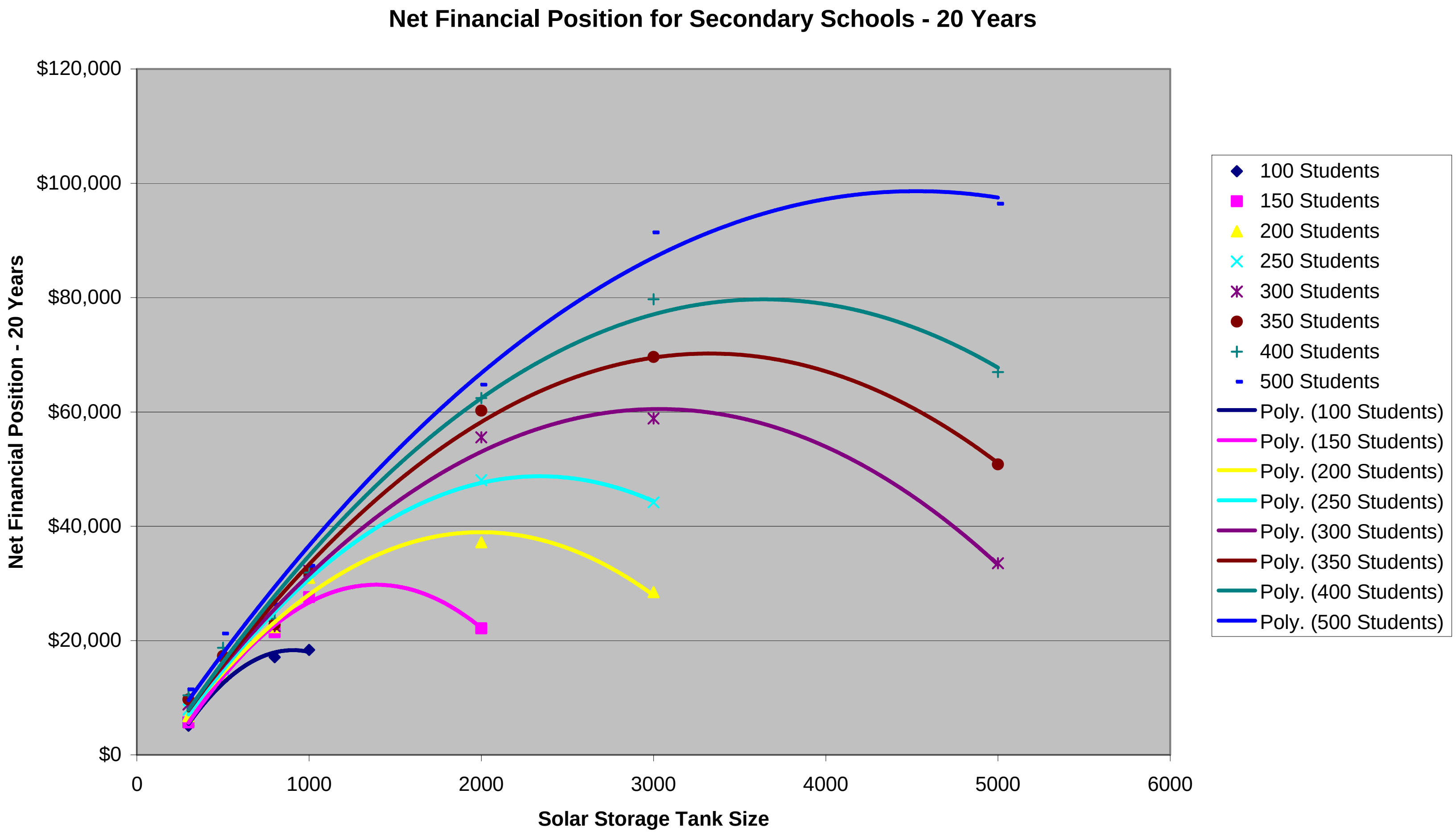

Figure 5-15: Secondary School net financial position complete with second order polynomial trend-lines

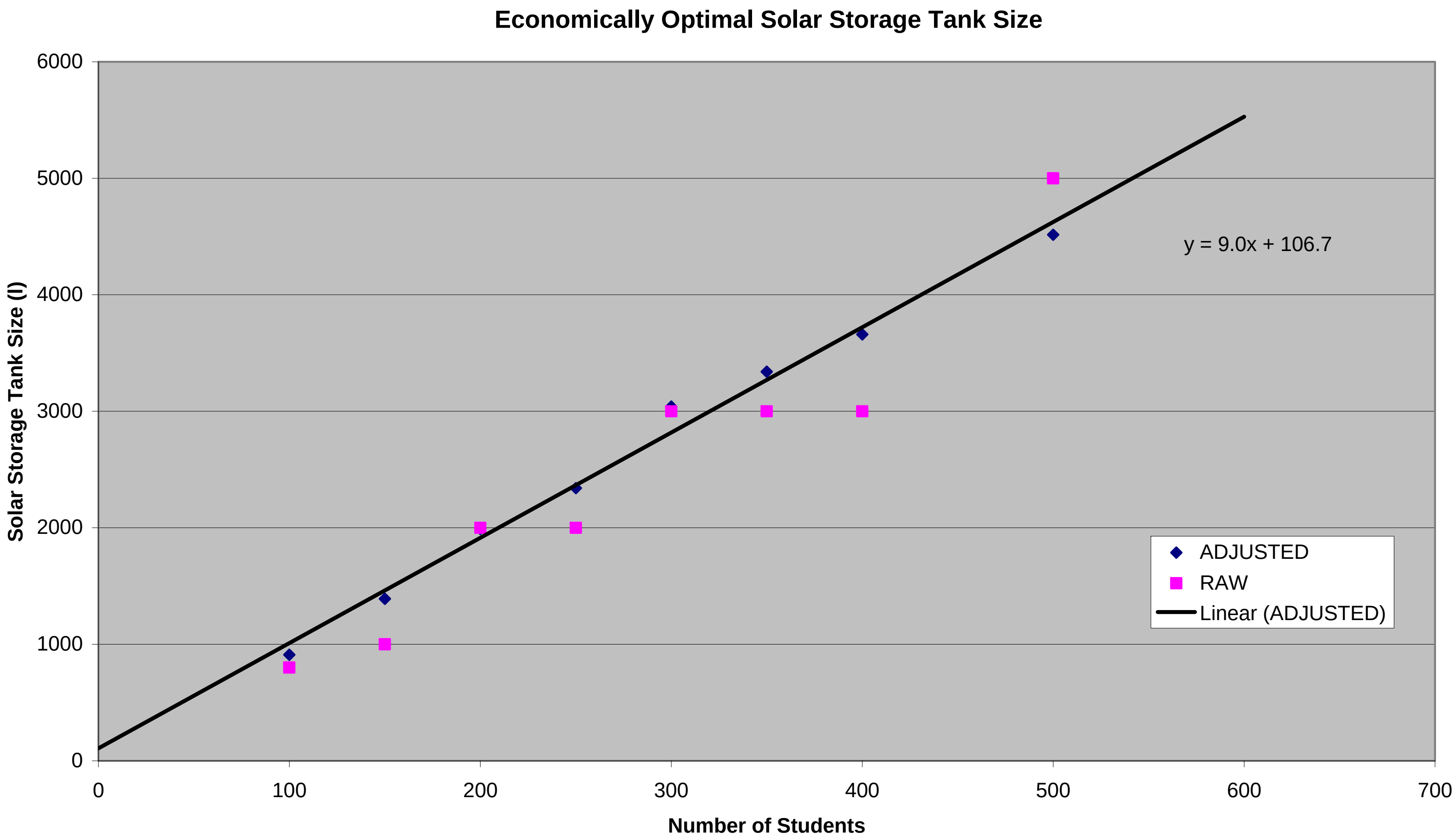

Figure 5-16: Secondary School economically optimal solar storage tank size

5.3 Discussion of Simulation Results

Each of the eight commercial applications indicates an economically optimal size for the storage tank, which is the point of reference of interest for the commercial industry. A second order polynomial has been used to fit the curve to predict the economically optimal point for different size commercial applications. Graphing the optimal size solar hot water storage tank for a number of sizes of commercial applications produces a linear relationship between the economically optimal capacity of the solar hot water storage and the size of the commercial application.

Below Table 5-9 summarises the optimal capacities from each of the commercial applications based on their linear relationship. The optimal sizes will enable a developer or an engineer to size a domestic solar hot water system to be economically optimal for the commercial application.

Table 5-9: Optimal Storage Capacity for Commercial Applications

Motels and Hotels	Optimal Capacity = 60l per bed + 640l
Apartments	Optimal Capacity = 200l per apartment + 490l
Retirement Homes	Optimal Capacity = 70l per bed + 310l
Offices	Optimal Capacity = 8l per person + 80l
Restaurants and Cafes	Optimal Capacity = 20l per meal + 30l
Fast Food Restaurants	Optimal Capacity = 3.5l per meal + 270l
Primary Schools	Optimal Capacity = 3.5l per person – 120l
Secondary Schools	Optimal Capacity = 9l per person +110l

The optimisation is based on a conservative energy cost of 19c/kWh with an annual inflation of 3%, while adjusting the price and affects the optimal sizing of the storage. Increasing the cost of energy improves the viability of having a domestic solar hot water system, which increases the size of the storage tank for an economic optimally sized system. Decreasing the cost, decreases the economic viability of domestic solar hot water systems, which reduces the size of the storage tank for an economic optimally sized system.

The solar hot water panel modelled was a highly efficient heat pipe type solar panel from Consol New Zealand Limited. The applied research test had the panel at 0.827 (or 82.7%) efficient with a low efficiency slope ensuring the solar hot water panel's efficiency does not drop off much when the inlet water temperature increases. Installing a less efficient panel has a similar effect of having lower energy price with a smaller storage tank being installed to achieve the economic optimally sized system.

The size of the solar hot water systems smaller than 1000l is limited to standard commercially available hot water cylinder sizes as custom cylinders are not economical. Hot water cylinders greater than 1000l are often made to order and almost any size cylinder can be made.

Each of the commercial application's domestic hot water profiles are based on average hourly percentage of hot water used throughout the day and multiplied by the average daily hot water consumption for the commercial application. This is a proportional relationship between the size of the commercial application and the amount of domestic hot water required. Figure 5-17 illustrates the economic optimisation of each of the eight commercial applications by using the average daily water consumed and the proportional relationship of the commercial application. It can be seen that all eight commercial applications have a similar proportional relationship between the daily hot water consumption and the economical optimal storage tank capacities however each of the application have their own proportional relationships.

Jordan and Vajen [18], Knudsen [19] and Bales and Persson [20] all concluded in their studies that the domestic hot water load profile is important in regards to the influence it has on the domestic solar hot water system. Figure 5-17 illustrates the differences the individual load profiles have on the economically optimal size of the solar hot water system. The graph illustrates each of the commercial applications have an independent profile, however there is also a definitive trend as each of the independent applications graphs have a similar slope. As the slopes and graphs are similar this identifies a generic relationship between the average daily hot water consumed and the economically optimal domestic solar hot water system size. This generic relationship is calculated and shown in Figure 5-18.

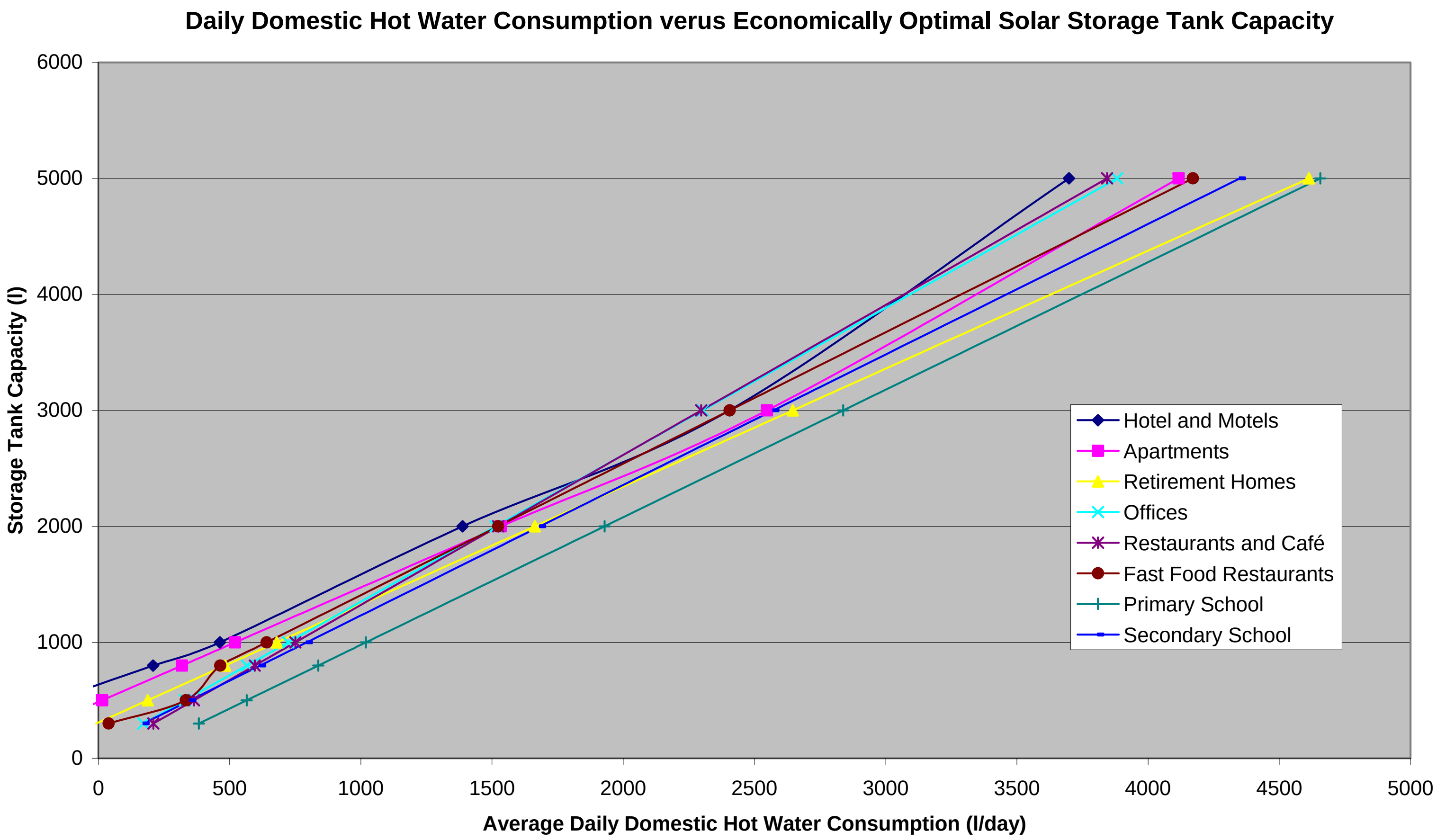

Figure 5-17: Comparison of commercial application optimisation based on average daily hot water consumption

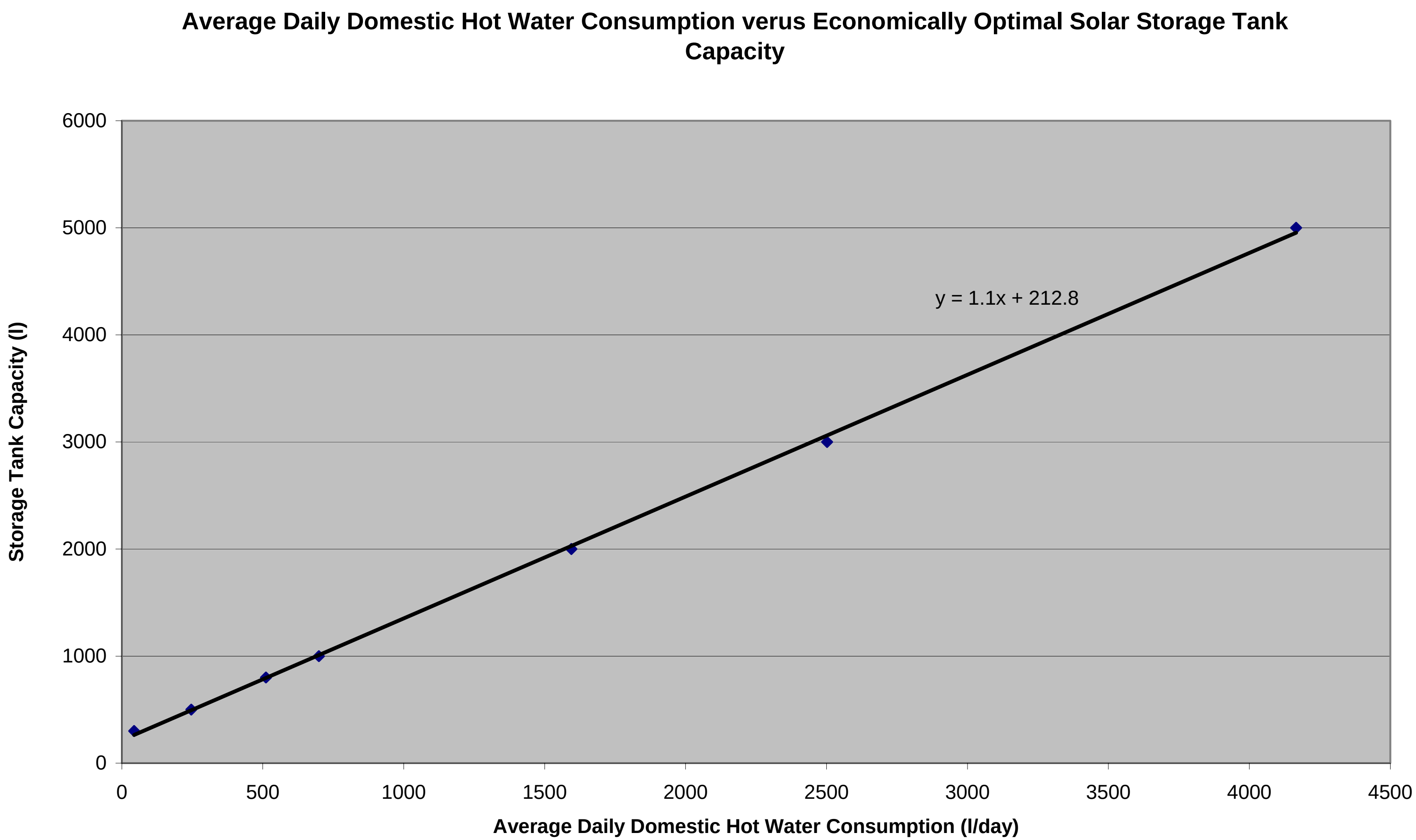

Figure 5-18: Averaged economic optimal storage tank based on daily hot water consumption

Figure 5-18 graphically represents the average proportional relationship between the economically optimal storage tank size and the average daily hot water consumed across the eight commercial applications. While this can only be used as a weak relationship, it captures a good rule of thumb for an initial size or preliminary design for any solar domestic hot water system. The rule of thumb has the storage tank being 110% of the daily hot water demand with an additional 210 litres.

Each of the commercial applications has a positive return over a twenty year period, as seen on each of the tables. Another important economic assessment of a solar domestic hot water system is the payback period. The payback period completes an assessment to when the savings outweigh the initial capital expense. In each of the eight commercial applications the payback is between ten and eleven years.

Several analyses were completed to explore the sensitivity of the key parameters and the impact on the results. The energy prices change the payback and economic analysis. Increasing the cost of energy ensured that the payback was achieved more rapidly and this increased the size of the economically optimal size of the domestic solar hot water system. Whereas, decreasing the cost of energy had the opposite effect, with increasing the time to payback the system and decreased the optimum size of the domestic solar hot water system.

The capital cost also affected the payback and economic analysis. An increase in the initial capital cost of the system increased the payback time, which decreased the size of the economically optimal size of the domestic solar hot water system. If there was a decrease in capital cost the payback was faster and increased the size of the economically optimal size of the domestic solar hot water system.

Results were also affected by changing the panel type to a traditional flat plate collector or changing the manufacturer of the evacuator tube. The applied research results identify the efficiency of the panel. Taking the Consol evacuator tube panel as the reference solar panel, a solar panel (either evacuator tube or flat plate) that has lower efficiency than the reference panel transfers less solar radiation to the domestic solar hot water system. Furthermore, it increases the payback time and decreases the size of the economically optimal domestic solar hot water system. A panel that is more efficient generally transfers more solar radiation to the domestic solar hot water system, decreases the payback time and increases the size of the economically optimal domestic solar hot water system. However, further analysis is required to explore if a flat plate collector has a higher efficiency as an evacuator tube panel may still transfer more solar radiation to the domestic hot water system. This maybe due to the evacuator tube panel re-radiating significantly less at higher temperatures and evacuator tubes being round which means there is more effective surface available than a flat plate collector when the sun is not perpendicular to the panel.

The final results of the economic optimisation of domestic solar hot water system for Christchurch complements conclusions drawn from previous studies by Thomas [1]. Thomas concluded for solar hot water systems in commercial buildings, for any climatological area the optimal fraction of load is independent of the load, and the optimal collector area is directly proportional to the load. This was evident in this study with the optimal storage tank being shown to have a linear relationship with the domestic hot water load.

6 Conclusion

In the course of this research, a proportional relationship was developed to economically optimise the size of commercial domestic solar hot water systems in Christchurch using the TRNSYS simulation program. Eight commercial applications each with individual domestic hot water load profiles were shown to have a proportional relationship between the economically optimal storage tank and the domestic hot water load. This relationship can be utilised to economically optimise the design of domestic solar hot water systems during the rebuild of Christchurch.

The simulation model was completed to adhere to the Australian and New Zealand Standards as this is the locally recognised simulation method.

The sponsors (Consol New Zealand Limited) heat pipe type evacuator tube panels were used as the solar collector. The panel's performance was assessed in August 2010 at an approved facility the Applied Research Services Limited test facility in Nelson.

A proportional relationship of 50l per net collector panel area was used based on previous studies. This enabled standard commercially available sized cylinders to be used to dictate a range of system sizes (8 system sizes analysed in total). Each of the systems analysed had a completed detailed price summary to enable an economic analysis for each system.

The TRNSYS simulation program was used to complete an annual simulation for the eight domestic solar hot water system sizes for each commercial application. A range of sizes for the eight commercial applications were analysed over the range of domestic solar hot water systems sized. Each individual simulation provided the annual energy savings for the domestic solar hot water systems for each circumstance. The annual energy saving from each simulation was economically evaluated over the expected life of the system (twenty years). This provided the data required to economically optimise the size of the domestic solar hot water system for the range of sizes of each commercial application.

To interpolate between the systems sizes for each application a second order polynomial was utilised. The second order polynomial enabled the economically optimal size of the domestic solar hot water system to be calculated for the specific size of the commercial application. This was completed for a range of sizes within the commercial applications. Plotting each of the economically optimal sizes against the size of the commercial application yielded a proportional relationship. The proportional relationship represents the relationship between the economically optimal size and the size of the domestic solar hot water system of the commercial application. A proportional relationship was identified for the eight commercial applications.

The size of the commercial application dictated the amount of domestic hot water required per day by another proportional relationship based on the type of commercial applications. Therefore, there is a proportional relationship between the economically optimal domestic solar hot water system size and the daily domestic hot water requirements for each commercial application.

As previously reviewed and outline outlined in previous studies the domestic hot water load profile is important with influencing the economically optimal size of the domestic solar hot water system. This is evident with the different proportional relationships between the economically optimal system size of a solar domestic hot water and the daily domestic hot water requirements for each commercial application. However, averaging each of the proportional relationships provides a weak averaged economically optimal sized solar hot water system based on the daily amount of domestic hot water consumed for any situation. The relationship is weak due to the influences seen from the domestic load profile on different commercial applications. However, this weak relationship produces a good conceptual economically optimal domestic solar hot water system size for designers of domestic hot water systems.

Recommendations for Future Work

Given additional resources it is the opinion of the author that future research investigated should:

- Analyse the economically optimal domestic solar hot water system size for other geographic locations around New Zealand.

- Analyse the economic optimisation with varying energy prices to identify a relationship between the economically optimal sized domestic solar hot water system and the price of energy.

- Analysis of economic optimisation with varying inflation rates to identify a relationship between the economically optimal sized domestic solar hot water system and the inflation rate.

- Investigate further other commercial applications or industrial processes for solar applications to make an economic case.

- Study the flow rates through the evacuator tube solar panels to further optimise the solar hot water system.

- Investigate domestic and commercial solar combi-systems and their economic applications in New Zealand.

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Appendix A - Component Inputs and Outputs

B - RADIATION TYPE 16g

#	Input Description	Units
1	Total radiation on horizontal surface	kJ/hr.m²
2	Direct normal beam radiation on horizontal	kJ/hr.m²
3	Time of last data read	hr
4	Time of next data read	hr
5	Ground reflectance	N/A
6	Slope of surface	degrees
7	Azimuth of surface	degrees

C - COLLECTOR TYPE 1b

#	Input Description	Units
1	Inlet temperature	°C
2	Inlet flowrate	kg/hr
3	Ambient temperature	°C
4	Incident radiation	kJ/hr.m²
5	Total horizontal radiation	kJ/hr.m²
6	Horizontal diffuse radiation	kJ/hr.m²
7	Ground reflectance	N/A
8	Incident angle	degrees
9	Collector slope	degrees

D - PUMP TYPE 3b

#	Input Description	Units
1	Input fluid temperature	°C
2	Inlet mass flow rate	kg/s
3	Control signal	N/A

E - SOLAR CONTROLLER TYPE 2a

#	Input Description	Units
1	Upper input temperature Th	°C
2	Lower input temperature Ti	°C
3	Monitoring temperature Tin	°C
4	Input control function	N/A
5	Upper dead band dT	N/A
6	Lower dead band dT	N/A

F - PRE-HEAT TANK TYPE 60c

#	Input Description	Units
1	Flow rate at inlet 1	kg/hr
2	Flow rate at outlet 1	kg/hr
3	Flow rate at inlet 2	kg/hr
4	Flow rate at outlet 2	kg/hr
5	Temperature at inlet 1	°C
6	Temperature at inlet 2	°C
7	Environment temperature	°C
8	Control signal for element 1	N/A
9	Control signal for element 2	N/A

G - PIPE TO COLLECTOR TYPE 31

#	Input Description	Units
1	Inlet temperature	°C
2	Inlet flowrate	kg/hr
3	Environment temperature	°C

H - PIPE FROM COLLECTOR TYPE 31

#	Input Description	Units
1	Inlet temperature	°C
2	Inlet flowrate	kg/hr
3	Environment temperature	°C

L - AUXILIARY HEAT TYPE 6

#	Input Description	Units
1	Inlet fluid temperature	°C
2	Inlet mass flow rate	kg/hr
3	Control function	N/A
4	Setpoint temperature	°C
5	Temperature of surroundings	°C

M - EQUATION

#	Input Description	Units
1	Input to equation editor 1	N/A
2	Input to equation editor 2	N/A
3	Input to equation editor 3	N/A

N - INTEGRATOR TYPE24

#	Input Description	Units
1	Input to be integrated 1	N/A
2	Input to be integrated 2	N/A
3	Input to be integrated 3	N/A
4	Input to be integrated 4	N/A
5	Input to be integrated 5	N/A

P - PRINTER TYPE24

#	Input Description	Units
1	Input to be printed 1	N/A
2	Input to be printed 2	N/A
3	Input to be printed 3	N/A
4	Input to be printed 4	N/A
5	Input to be printed 5	N/A

Q - TEMP PLOTTER TYPE65

#	Input Description	Units
1	Left axis variable 1	N/A
2	Left axis variable 2	N/A
3	Left axis variable 3	N/A
4	Left axis variable 4	N/A
5	Left axis variable 5	N/A
6	Left axis variable 6	N/A
7	Right axis variable 1	N/A

A - WEATHER INPUT TYPE 89c

#	Output Description	Units
3	Direct normal radiation	kJ/hr.m²
4	Global horizontal radiation	kJ/hr.m²
5	Dry bulb temperature	°C
99	Time of last read	hr
100	Time of next read	hr

B - RADIATION TYPE 16g

#	Output Description	Units
4	Total horizontal radiation	kJ/hr.m²
6	Horizontal diffuse radiation	kJ/hr.m²
7	Total radiation on surface 1	kJ/hr.m²
10	Incident angle for surface 1	degrees
11	Slope of surface 1	degrees

C - COLLECTOR TYPE 1b

#	Output Description	Units
1	Outlet temperature	°C
2	Outlet flow rate	kg/hr
3	Useful energy gain	kJ/hr

D - PUMP TYPE 3b

#	Output Description	Units
1	Outlet fluid temperature	°C
2	Outlet flow rate	kg/s
3	Power consumption	kJ/hr

E - SOLAR CONTROLLER TYPE 2a

#	Output Description	Units
1	Output control function	N/A

F - PRE-HEAT TANK TYPE 60c

#	Output Description	Units
2	Flow rate at outlet 1	kg/hr
5	Temperature of outlet flow 1	°C
6	Temperature of outlet flow 2	°C
7	Thermal Losses	kJ/hr
27	Tank temperature top	°C
28	Tank temperature bottom	°C

G - PIPE TO COLLECTOR TYPE 31

#	Output Description	Units
1	Outlet temperature	°C
2	Outlet flowrate	kg/hr
3	Environmental losses	kJ/hr

H - PIPE FROM COLLECTOR TYPE 31

#	Output Description	Units
1	Outlet temperature	°C
2	Outlet flowrate	kg/hr
3	Environmental losses	kJ/hr

J - WH TEMP TYPE 14e

#	Output Description	Units
2	Instantaneous temperature	°C

K - LOAD DEMAND TYPE 14b

#	Output Description	Units
2	Instantaneous water draw	kg/hr

L - AUXILIARY HEAT TYPE 6

#	Output Description	Units
1	Outlet fluid temperature	°C
5	Rate of energy delivery to fluid stream	kJ/hr

M - EQUATION

#	Output Description	Units
1	Input1 + Input2 + Input3	kJ/hr

N - INTEGRATOR TYPE 24

#	Output Description	Units
1	Result of integration 1	N/A
2	Result of integration 2	N/A
3	Result of integration 3	N/A
4	Result of integration 4	N/A
5	Result of integration 5	N/A

Appendix B - Applied Research Panel Test Results

APPLIED RESEARCH
SERVICES LIMITED
(SUBJECT TO DEED OF COMPANY ARRANGEMENT)

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Testing of the Consol D58-1800-18 Evacuated Tube Solar Collector to AS / NZS 2535

Customer: Consol NZ Ltd
PO Box 36409
CHRISTCHURCH 8146

Report 10/2291

August 2010

APPLIED RESEARCH SERVICES LIMITED

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Customer: **Consol NZ Ltd**
PO Box 36409
Christchurch 8146

P1514/6

Attention: **Matt Wheelans**

Testing of the Consol D58-1800-18 Evacuated Tube Solar Collector to AS / NZS 2535

1.0 Introduction

A sample of the Consol D58-1800-18 evacuated tube solar collector was tested to the requirements of AS/NZS2535.

Supplier:	Consol NZ Ltd
Collector model:	D58-1800-18
Test Personnel:	G Looman
Location of Tests:	Rotheram St Laboratory
Month of Testing:	June to August 2010

1.1 Accreditation

Laboratory Registration Number 395

This laboratory is accredited by International Accreditation New Zealand (IANZ). Only tests, measurements or associated inspections are covered by IANZ accreditation.

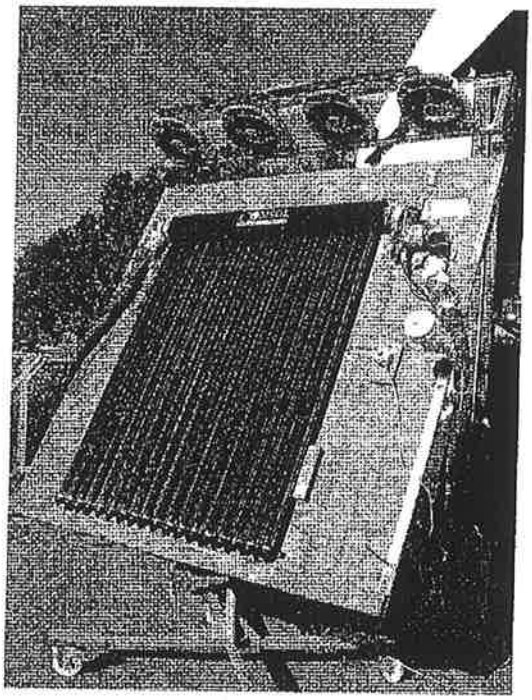
new zealand accredited laboratory

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Accreditation does not extend to the qualitative information contained in this report such as interpretations, opinions and supplier statements.

IANZ has a Mutual Recognition Arrangement (MRA) with the National Association of Testing Authorities (NATA), Australia, such that both organizations recognize accreditations by IANZ and NATA as being equivalent. Users of test reports are recommended to accept test reports in the name of either accrediting body.

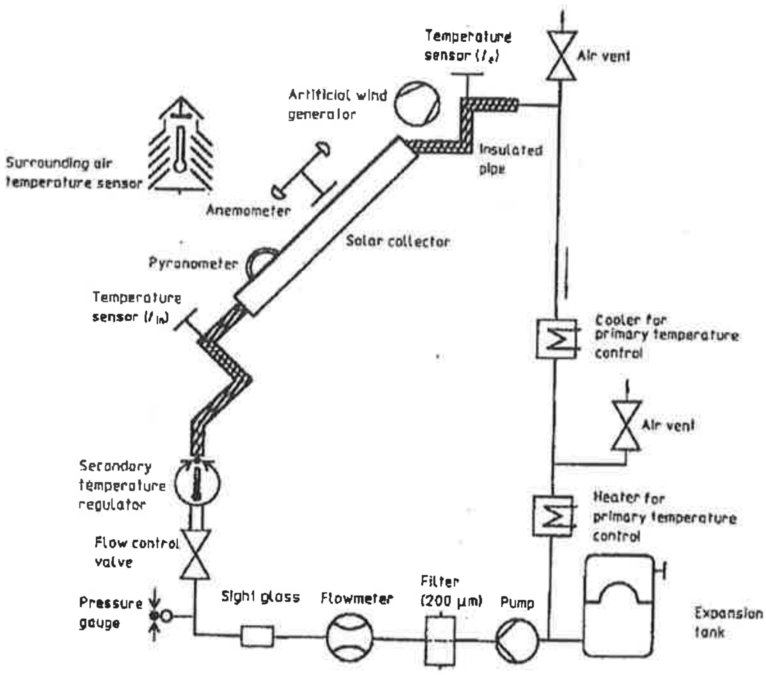
Figure 1. Photograph of the collector tested



1.2 Test Procedures

The outdoor steady state efficiency test procedures were based on the requirements of AS/NZS 2535.1:2007 sections 5 to 8 and section 11. All testing was performed outdoors. The preconditioning of the collector, as described in section 8.2, of the standard was not confirmed.

Figure 2. Schematic Diagram of the Test Loop



2.0 Details of the Collector

2.1 Information Provided by Manufacturer

There was no information supplied by the manufacturer.

2.2 Description

The collector has double walled evacuated tubes containing an aluminium heat transfer sheet and heat pipe. Sunlight falling on the tubes is converted to heat within the tube. The aluminium sheet conducts the heat to the copper heat pipe. The heat transfer fluid contained within the heat pipe then transfers the heat to water flowing through the manifold at the top of the heat pipes.

2.3 General details

Collector Type:	Evacuated tube with Heat pipes
Model Number:	D58-1800-18
Serial No:	D58180018201003102 2
Serial product or prototype:	Serial
Year of Production:	2010
Total mass of collector: without fluid, kg:	56.13

2.4 Dimensions of collector unit

Width, mm:	1500
Length, mm:	1980
Height, mm:	140
Gross area, m^2:	2.89
Absorber area, m^2:	1.49
Aperture area, m^2:	1.71

2.5 Collector tubes

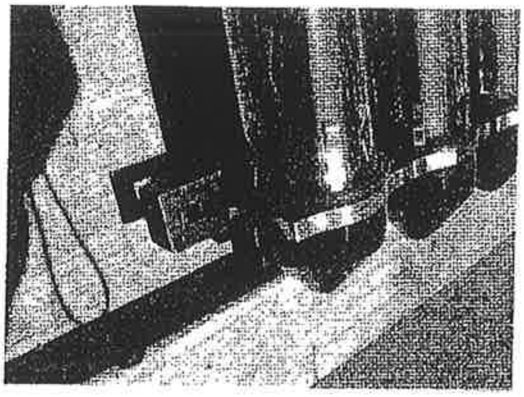
The collector tubes have four components. The outer is a double walled evacuated tube. In the tube is a rolled and folded aluminium sheet that fits tightly against the inner wall of the tube. This sheet encloses a copper heat pipe. The top of the tube has a plug of aluminium with a rubber layer that seals the top of the tube, and allows the heat pipe to pass through it. The evacuated tube has a selective coating applied to the inside of the internal tube that is copper coloured from the inside and dark blue on the outside.

Tube overall length (glass only), mm:	1820
Outer tube outside diameter, mm:	58
Outer tube inside diameter, mm:	54.8
Inner tube outside diameter, mm:	47.6
Inner tube inside diameter, mm:	44.4
Heat pipe diameter, mm:	8
Heat pipe transfer section diameter, mm:	13.8
Heat pipe transfer section length, mm:	44
Heat pipe overall length, mm:	1700
Weight of typical tube (glass only), kg:	2
Absorber material:	Glass

Surface treatment:	Selective coating
Absorber diameter, mm:	47.6
Absorber length, mm:	1735 exposed

A rubber boot is fitted to the lower end of each evacuated tube. The lower frame rail has raised lugs to position the tubes, and a stainless steel clip holds the tube in place.

Figure 3. Detail Showing Frame Attachment



2.6 Manifold

The manifold is a copper pipe running through the centre of a manifold box. The manifold is contained in an aluminium manifold box and is surrounded by fibreglass insulation.

Length overall, mm:	1580
Length of box, mm:	1495
Width, mm:	122
Height, mm:	100
Number of tubes:	18
Tube centres, mm:	80
Distance from tube centre to bottom of box, mm:	50
Inlet connection:	22mm OD pipe
Outlet connection:	22mm OD pipe
Insulation type:	Fibreglass
Sheathing material:	Aluminium

Where the heat pipes enter the manifold a tube is brazed into the pipe that the heat pipe transfer section slides into. The evacuated tubes have rubber dust seals at the entry to the manifold box.

2.7 Frame

The frame is a simple rectangle formed by the manifold box at the top, two c-section side rails and a c-section bottom rail. All rails have grooves in the sides. These grooves are used to fasten the frame together by stainless steel plates locating in the groove on one rail and bolted to the second rail.

2.8 Heat transfer medium

The heat transfer medium is the fluid transferring heat between the solar collector and the storage cylinder.

Type:	Water
Specifications:	No Additives

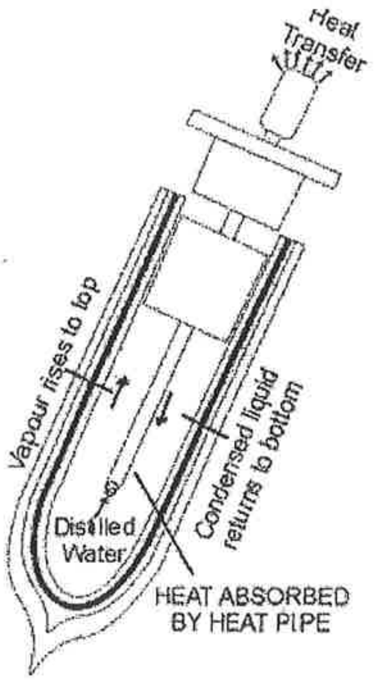
Alternative acceptable heat transfer fluids:	Glycol and Water

2.9 Limitations

Maximum temperature of operation, °C:	Not stated
Maximum pressure, kPa:	8 bar
Other limitations:	Not stated

2.10 Schematic diagram of solar collector

Figure 4 Schematic diagram of solar collector



3.0 Test Results

3.1 Uncertainties of Measurement

Temperature measurements, °C:	0.1
Pressure measurement, kPa:	10
Length measurement (with tape), mm:	3
Length measurement (with callipers),mm:	0.1
Radiation measurement, W/m^2:	10
Elapsed time, %:	0.1

3.2 Symbols and units

Symbol	Meaning	Units
a_1	Algebraic constant, reference to T_i^*	W/(m^{2}K)
a_2	Algebraic constant, reference to T_i^*	W/(m^{2}K^2)

$\overline{a}_1$	Algebraic constant, reference to T_m^*	W/(m²K)
$\overline{a}_2$	Algebraic constant, reference to T_m^*	W/(m²K²)
$\overline{a}_{1A}$	Algebraic constant, reference to T_m^* and aperture area	W/(m²K)
$\overline{a}_{2G}$	Algebraic constant, reference to T_m^* and gross area	W/(m²K²)
A_A	Absorber area of collector	m²
A_a	Aperture area of collector	m²
A_G	Gross area of collector	m²
D	Date	DDMMYY
c_f	Specific heat capacity of heat transfer fluid	J/(kg K)
G	Global solar irradiance	W/m²
LT	Local time	h
K_θ	Incident angle modifier	--
$\dot{m}$	Mass flow rate of heat transfer fluid	kg/s
$\dot{Q}$	Useful power extracted from collector	W
t	Time	s
t_a	Ambient or surrounding air temperature	°C
t_e	Collector outlet (exit) temperature	°C
t_{in}	Collector inlet temperature	°C
t_m	Mean temperature of heat transfer fluid	°C
T_i^*	Reduced temperature difference referred to inlet	m²K/W
T_m^*	Reduced temperature difference referred to mean	m²K/W
U	Measured overall heat loss coefficient of collector with reference to T_i^*	W/(m²K)
$\overline{U}$	Measured overall heat loss coefficient of collector with reference to T_m^*	W/(m²K)
u	Surrounding air speed	m/s
ΔT	Temperature difference between fluid outlet and inlet ($t_e - t_{in}$)	K
η	Collector thermal efficiency, with reference to T_i^*	--
$\overline{\eta}$	Collector thermal efficiency, with reference to T_m^*	--
η_0	Eta zero (η at $T_i^* = 0$), reference to T_i^*	--
ρ	Density of heat transfer fluid	kg/m³

Subscripts

A	Reference to absorber area
G	Reference to gross collector area

3.3 Test results

Latitude:	41°18' S
Longitude:	173°16' E
Local time at solar noon: h-min:	12:32

3.3.1 Measured data

Date DDMMYY	LT h-min	G W/m^2	t_a °C	u m/s	t_{in} °C	t_e-t_{in} K	$\dot{m}$ kg/s
9/07/10	13:47	925	16.8	2.24	16.7	4.6	0.059
9/07/10	13:29	933	17.2	2.21	16.7	4.6	0.060
9/07/10	13:05	944	17.1	2.39	16.6	4.6	0.059
9/07/10	12:24	939	16.4	2.20	16.0	4.6	0.060
9/07/10	10:54	886	13.8	2.11	32.4	3.9	0.060
2/07/10	14:56	830	17.4	2.17	29.2	4.1	0.060
2/07/10	14:37	862	17.7	2.60	29.4	4.2	0.060
2/07/10	14:19	886	17.9	2.18	29.5	4.3	0.061
2/07/10	12:48	934	17.9	2.14	52.8	3.9	0.063
2/07/10	12:24	930	17.5	2.36	52.7	3.9	0.062
2/07/10	11:39	913	16.6	2.42	52.6	3.8	0.061
1/07/10	12:58	900	14.8	2.17	51.6	3.8	0.062
30/06/10	13:47	888	14.6	2.46	71.2	3.7	0.063
30/06/10	13:23	924	14.5	2.24	71.2	3.7	0.063
30/06/10	13.03	894	14.8	2.23	71.3	3.7	0.063
30/06/10	12:46	894	15.2	2.13	71.3	3.7	0.063

3.3.2 Derived data

Date DDMMYY	LT h-min	t_m °C	C_f J/(kg K)	$\dot{Q}$ W	$\frac{t_m-t_a}{G}$ m^2K/W	$\frac{t_{in}-t_a}{G}$ m^2K/W	η_G	η_A
9/07/10	13:47	18.96	4183	1124	0.002	-0.000	42.03	81.72
9/07/10	13:29	18.96	4183	1143	0.002	-0.001	42.42	82.46
9/07/10	13:05	18.94	4183	1145	0.002	-0.001	41.98	81.61
9/07/10	12:24	18.30	4183	1142	0.002	-0.000	42.09	81.83
9/07/10	10:54	34.40	4177	990	0.023	0.021	38.66	75.16
2/07/10	14:56	31.21	4178	1013	0.017	0.014	42.26	82.16
2/07/10	14:37	31.45	4178	1046	0.016	0.014	42.02	81.70
2/07/10	14:19	31.59	4178	1079	0.015	0.013	42.15	81.94
2/07/10	12:48	54.80	4184	1032	0.039	0.037	38.24	74.34
2/07/10	12:24	54.68	4184	1011	0.040	0.038	37.62	73.14
2/07/10	11:39	54.53	4184	969	0.042	0.039	36.73	71.42
1/07/10	12:58	53.48	4183	983	0.043	0.041	37.80	73.49
30/06/10	13:47	73.09	4197	970	0.066	0.064	37.80	73.50
30/06/10	13:23	73.10	4197	989	0.063	0.061	37.04	72.02
30/06/10	13.03	73.09	4197	968	0.065	0.063	37.48	72.86
30/06/10	12:46	73.12	4197	972	0.065	0.063	37.60	73.09

3.4 Instantaneous Efficiency Curve Based on Gross Area and Fluid Mean Temperature

The gross area was calculated as the maximum projected area of the complete collector, excluding any integral means of mounting and connecting fluid pipe work as per ISO 9488:1999 (E/F) section 8.7.

The instantaneous efficiency is defined by: $\eta_G = \dot{Q}/(A_G.\ G)$

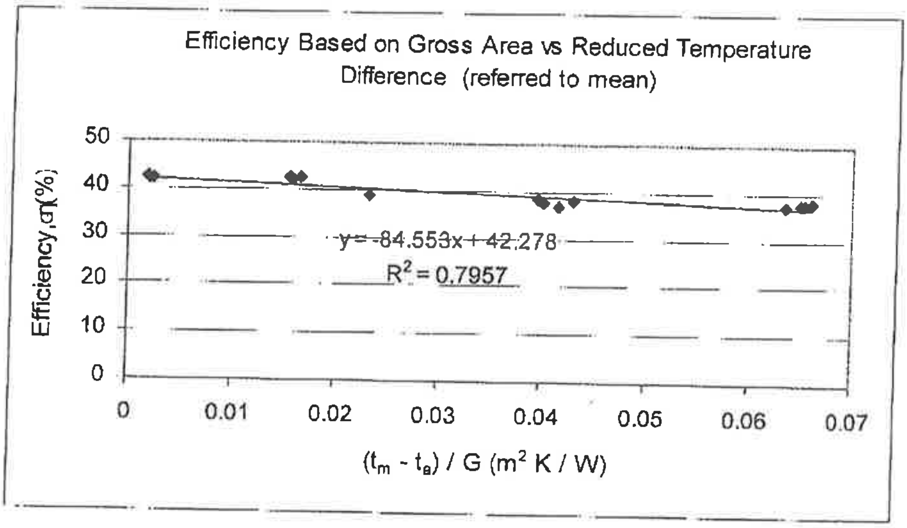
Where:

$\dot{Q}$ = Power extracted (W)

G = Solar radiation (W/m^2)

Gross area used for curve: A_G = 2.89m^2
Fluid flow rate used for the tests: $\dot{m}$ = 0.06kg/s

3.4.1 Linear fit to data

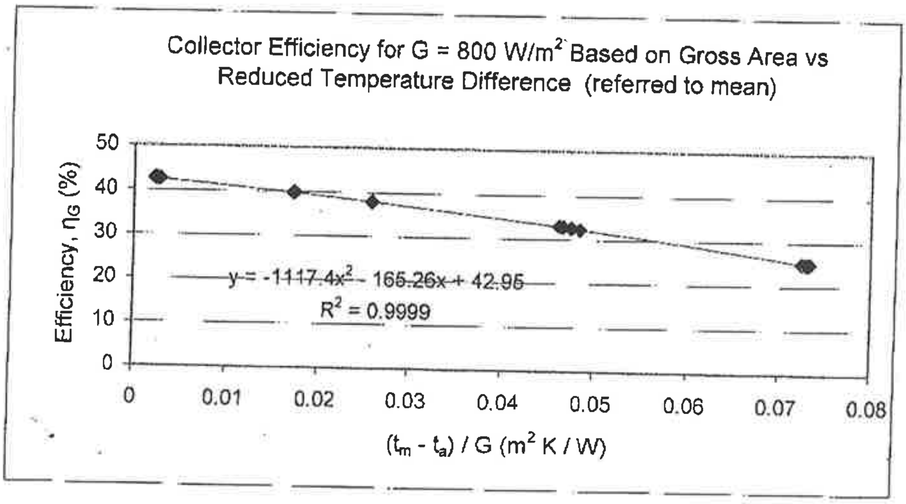


$\bar{\eta}_G = \bar{\eta}_{OG} - \bar{U}_G (t_m - t_a)/G$

$\bar{\eta}_{OG}$ = 42.278

$\bar{U}_G$ = 84.553 W/(m^2.K)

3.4.2 Second-order fit to data with G = 800W/m^2



$\bar{\eta}_G = \bar{\eta}_{OG} - \bar{a}_{1G}.(t_m-t_a)/G - \bar{a}_{2G}.G.((t_m-t_a)/G)^2$

$\bar{\eta}_{OG}$ = 42.95

$\bar{a}_{1G}$ = 165.26 W/(m^2.K)

$\bar{a}_{2G}$ = 1.397 W/(m^2.K^2)

3.5 Instantaneous Efficiency Curve Based on Gross Area and Fluid Inlet Temperature

The gross area was calculated as the maximum projected area of the complete collector, excluding any integral means of mounting and connecting fluid pipe work as per ISO 9488:1999 (E/F) section 8.7.

The instantaneous efficiency is defined by: $\eta_G = \dot{Q}/(A_G \cdot G)$

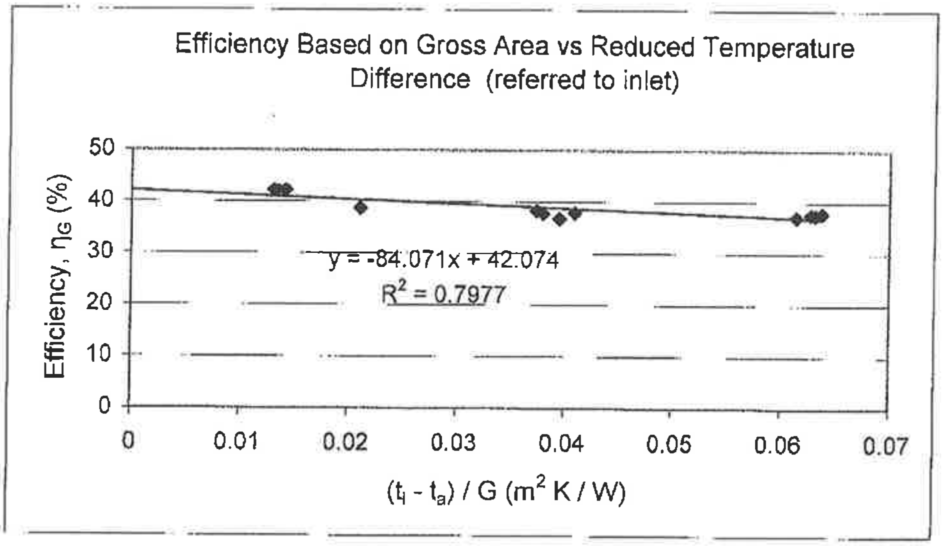
Where: $\dot{Q}$ = Power extracted (W)

G = Solar radiation (W/m^2)

Gross area used for curve: $A_G = 2.89m^2$

Fluid flow rate used for the tests: $\dot{m} = 0.06kg/s$

3.5.1 Linear fit to data

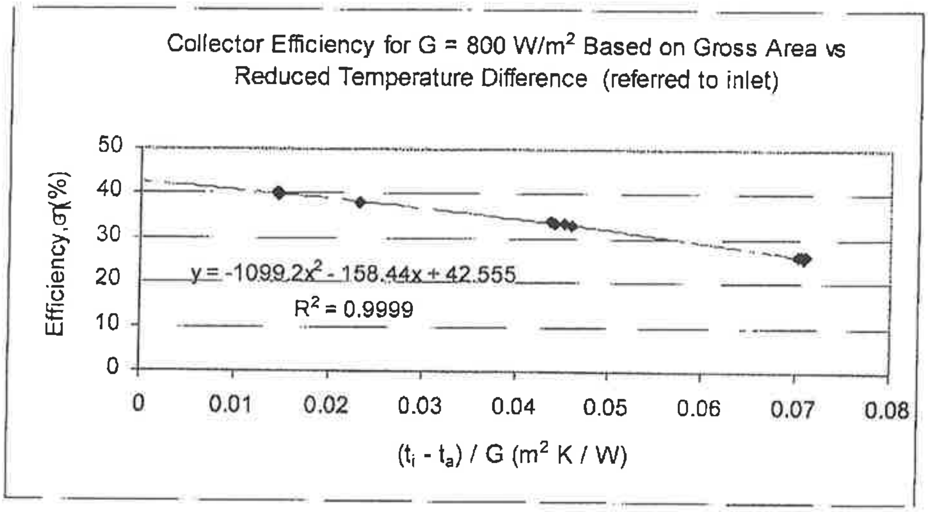


$\eta_G = \eta_{0G} - U_G (t_i - t_a)/G$

$\eta_{0G} = 42.074$

$U_G = 84.071 W/(m^2.K)$

3.5.2 Second-order fit to data with G = 800W/m²



$\eta_G = \eta_{0G} - a_{1G}.(t_i-t_a)/G - a_{2G}.G.((t_i-t_a)/G)^2$

$\eta_{0G} = 42.555$

$a_{1G} = 158.44 W/(m^2.K)$

$a_{2G} = 1.374 W/(m^2.K^2)$

3.6 Instantaneous Efficiency Curve Based on Absorber Area and Fluid Mean Temperature

The absorber area, A_A was calculated as per ISO 9488:1999 (E/F) section 8.9

The instantaneous efficiency is defined by: $\bar{\eta}_A = \dot{Q}/(A_A \cdot G)$

Where:

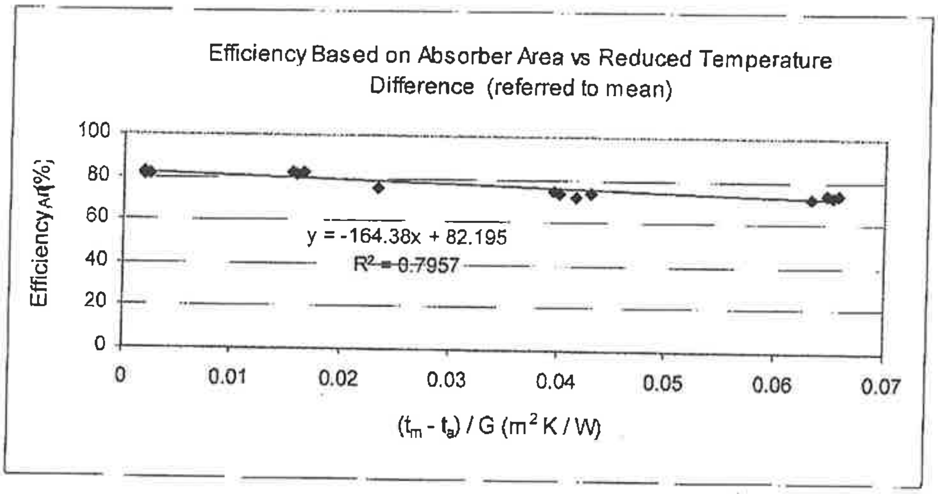
$\dot{Q}$ = Power extracted, W

G = Solar radiation, W/m^2

Absorber area used for curve: A_A = 1.49m2

Fluid flow rate used for the tests: $\dot{m}$ = 0.06kg/s

3.6.1 Linear fit to data

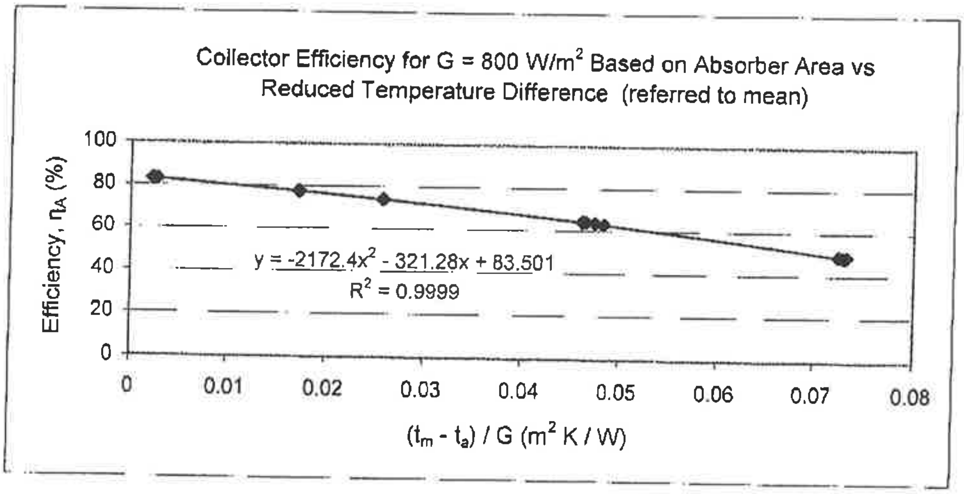


$\bar{\eta}_A = \bar{\eta}_{OA} - \bar{U}_A (t_m - t_a)/G$

$\bar{\eta}_{OA}$ = 82.195

$\bar{U}_A$ = 164.38 $W/(m^2.K)$

3.6.2 Second-order fit to data with G = 800W/m^2



$\bar{\eta}_A = \bar{\eta}_{OA} - \bar{a}_{1A}.(t_m-t_a)/G - \bar{a}_{2A}.G.((t_m-t_a)/G)^2$

$\bar{\eta}_{OA}$ = 83.501

$\bar{a}_{1A}$ = 321.28 $W/(m^2.K)$

$\bar{a}_{2A}$ = 2.716 $W/(m^2.K^2)$

3.7 Instantaneous Efficiency Curve Based on Absorber Area and Fluid Inlet Temperature

The absorber area, A_A was calculated as per ISO 9488:1999 (E/F) section 8.9

The instantaneous efficiency is defined by: $\eta_A = \dot{Q}/(A_A \cdot G)$

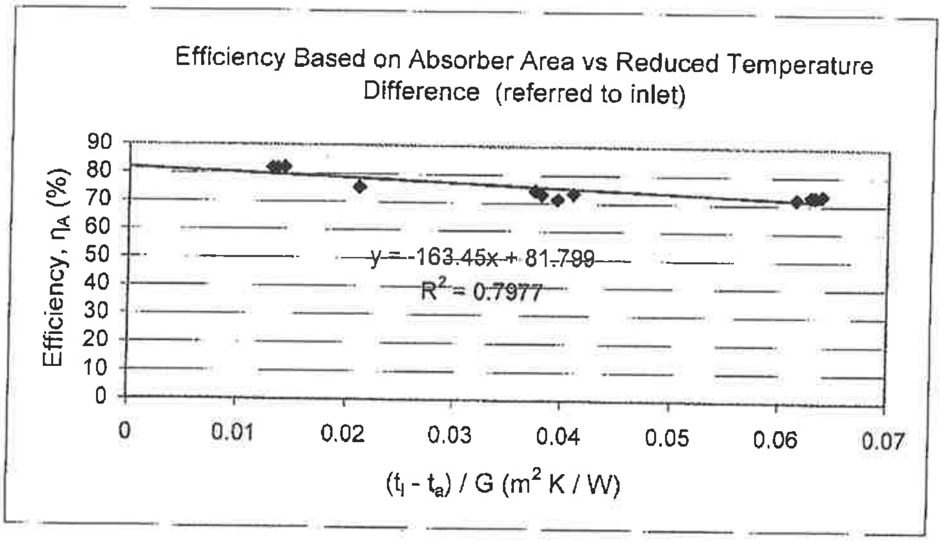
where $\dot{Q}$ = Power extracted, W

G = Solar radiation, W/m^2

Absorber area used for curve: A_A = 1.49m2

Fluid flow rate used for the tests : $\dot{m}$ = 0.06kg/s

3.7.1 Linear fit to data

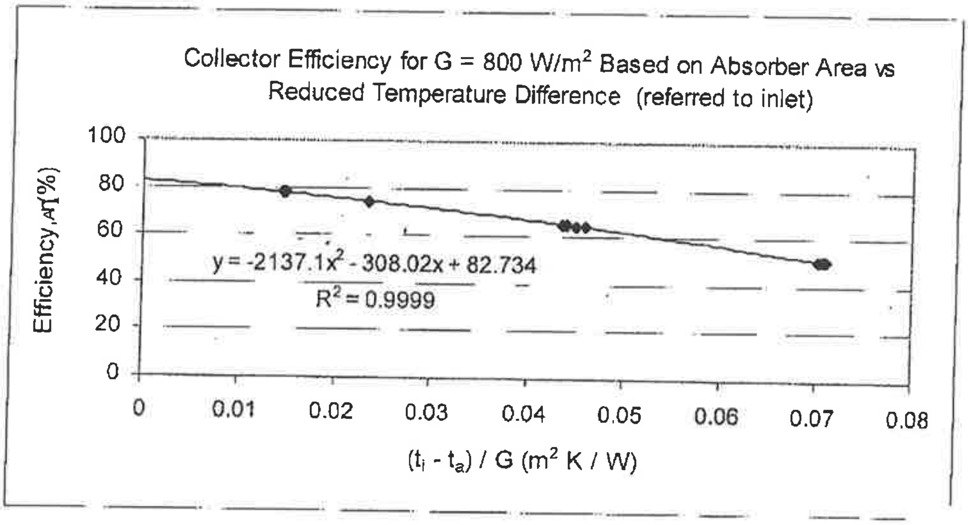


$\eta_A = \eta_{0A} - U_A (t_i - t_a)/G$

η_{0A} = 81.799

U_A = 163.45 W/(m^2.K)

3.7.2 Second-order fit to data with G = 800W/m^2



$\eta_A = \eta_{0A} - a_{1A}.(t_i-t_a)/G - a_{2A}.G.((t_i-t_a)/G)^2$

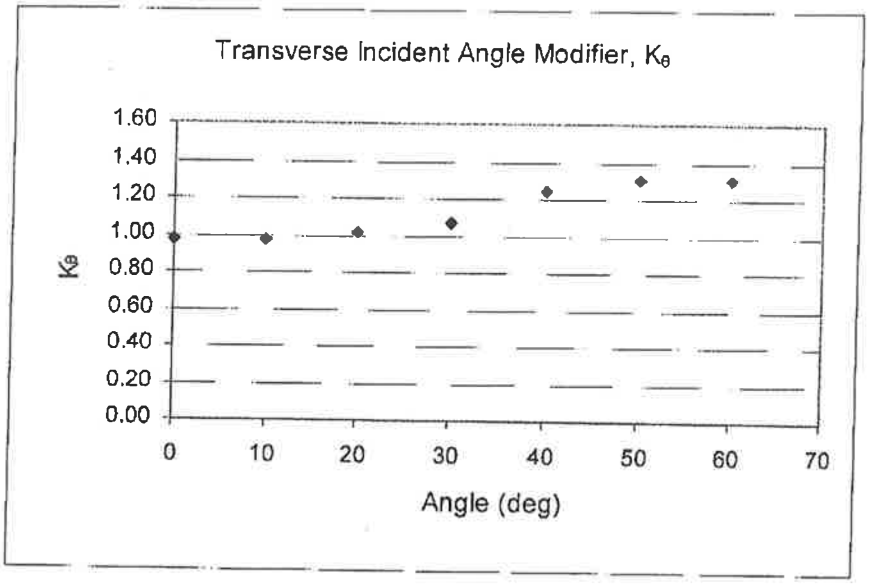
η_{0A} = 82.734

a_{1A} = 308.02 W/(m^2.K)
a_{2A} = 2.671 W/(m^2.K^2)

3.8 Incident Angle Modifier, K_θ

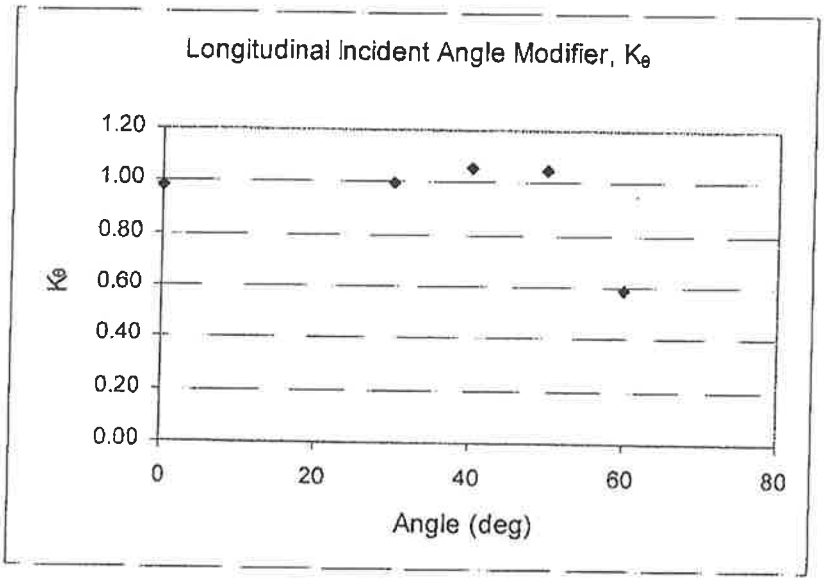
3.8.1 Transverse

Angle (deg)	0	10	20	30	40	50	60
K_θ	0.98	0.98	1.02	1.06	1.24	1.30	1.30



3.8.2 Longitudinal

Angle (deg)	0	30	40	50	60
K_θ	0.98	1.00	1.05	1.05	0.59



This report relates only to the product sample tested. Any modifications to the product may invalidate the results.

This report:

Prepared by: G. Looman

Approved by: P. Wilkie Peter Wilkie.

Release Date: 25/8/10

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Appendix 1 Collector Details Supplied by the Manufacturer

No details were supplied by the manufacturer.

Appendix C - Detailed Domestic Solar Hot Water System Prices

Solar Hot Water System Price Schedule

System: 3000l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	24	$ 48,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00		$ -
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00		$ -
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00	1	$ 1,200.00
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00		$ -
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00		$ -
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00		$ -
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00		$ -
	2,000l Cylinder	Custom Cylinder	$ 12,000.00		$ -
	3,000l Cylinder	Custom Cylinder	$ 20,000.00	1	$ 20,000.00
	5,000l Cylinder	Custom Cylinder	$ 30,000.00		$ -
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30		$ -
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10		$ -
	25mm Copper	25mm dia, per meter rate	$ 46.30	140	$ 6,482.00
	32mm Copper	32mm dia, per meter rate	$ 67.00		$ -
	40mm Copper	40mm dia, per meter rate	$ 79.00	10	$ 790.00
	50mm Copper	50mm dia, per meter rate	$ 102.00		$ -
	15mm Insulation	13mm flexible closed cell	$ 16.30		$ -
	20mm Insulation	13mm flexible closed cell	$ 19.90		$ -
	25mm Insulation	13mm flexible closed cell	$ 21.50	140	$ 3,010.00
	32mm Insulation	13mm flexible closed cell	$ 22.20		$ -
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00	10	$ 320.00
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70		$ -
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00		$ -
		Medium System	$ 5,000.00	1	$ 5,000.00
		Large System	$ 12,000.00		$ -
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$85,322.00**

Solar Hot Water System Price Schedule

System: 300l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	2	$ 4,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00	1	$ 495.00
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00		$ -
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00		$ -
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00	1	$ 2,000.00
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00		$ -
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00		$ -
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00		$ -
	2,000l Cylinder	Custom Cylinder	$ 12,000.00	0	$ -
	3,000l Cylinder	Custom Cylinder	$ 20,000.00		$ -
	5,000l Cylinder	Custom Cylinder	$ 30,000.00		$ -
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30	30	$ 969.00
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10		$ -
	25mm Copper	25mm dia, per meter rate	$ 46.30	10	$ 463.00
	32mm Copper	32mm dia, per meter rate	$ 67.00		$ -
	40mm Copper	40mm dia, per meter rate	$ 79.00		$ -
	50mm Copper	50mm dia, per meter rate	$ 102.00		$ -
	15mm Insulation	13mm flexible closed cell	$ 16.30	30	$ 489.00
	20mm Insulation	13mm flexible closed cell	$ 19.90		$ -
	25mm Insulation	13mm flexible closed cell	$ 21.50	10	$ 215.00
	32mm Insulation	13mm flexible closed cell	$ 22.20		$ -
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00		$ -
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70		$ -
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00	1	$ 500.00
		Medium System	$ 5,000.00		$ -
		Large System	$ 12,000.00		$ -
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$9,651.00**

Solar Hot Water System Price Schedule

System: 500l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	4	$ 8,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00	1	$ 495.00
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00		$ -
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00		$ -
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00		$ -
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00	1	$ 3,500.00
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00		$ -
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00		$ -
	2,000l Cylinder	Custom Cylinder	$ 12,000.00		$ -
	3,000l Cylinder	Custom Cylinder	$ 20,000.00		$ -
	5,000l Cylinder	Custom Cylinder	$ 30,000.00		$ -
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30	40	$ 1,292.00
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10		$ -
	25mm Copper	25mm dia, per meter rate	$ 46.30	10	$ 463.00
	32mm Copper	32mm dia, per meter rate	$ 67.00		$ -
	40mm Copper	40mm dia, per meter rate	$ 79.00		$ -
	50mm Copper	50mm dia, per meter rate	$ 102.00		$ -
	15mm Insulation	13mm flexible closed cell	$ 16.30	40	$ 652.00
	20mm Insulation	13mm flexible closed cell	$ 19.90		$ -
	25mm Insulation	13mm flexible closed cell	$ 21.50	10	$ 215.00
	32mm Insulation	13mm flexible closed cell	$ 22.20		$ -
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00		$ -
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70		$ -
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00	1	$ 500.00
		Medium System	$ 5,000.00		$ -
		Large System	$ 12,000.00		$ -
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$15,637.00**

Solar Hot Water System Price Schedule

System: 800l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	6	$ 12,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00	1	$ 495.00
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00		$ -
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00		$ -
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00		$ -
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00		$ -
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00	1	$ 5,200.00
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00		$ -
	2,000l Cylinder	Custom Cylinder	$ 12,000.00		$ -
	3,000l Cylinder	Custom Cylinder	$ 20,000.00		$ -
	5,000l Cylinder	Custom Cylinder	$ 30,000.00		$ -
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30		$ -
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10	50	$ 2,155.00
	25mm Copper	25mm dia, per meter rate	$ 46.30		$ -
	32mm Copper	32mm dia, per meter rate	$ 67.00	10	$ 670.00
	40mm Copper	40mm dia, per meter rate	$ 79.00		$ -
	50mm Copper	50mm dia, per meter rate	$ 102.00		$ -
	15mm Insulation	13mm flexible closed cell	$ 16.30		$ -
	20mm Insulation	13mm flexible closed cell	$ 19.90	50	$ 995.00
	25mm Insulation	13mm flexible closed cell	$ 21.50		$ -
	32mm Insulation	13mm flexible closed cell	$ 22.20	10	$ 222.00
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00		$ -
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70		$ -
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00	1	$ 500.00
		Medium System	$ 5,000.00		$ -
		Large System	$ 12,000.00		$ -
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$22,757.00**

Solar Hot Water System Price Schedule

System: 1000l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	8	$ 16,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00		$ -
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00	1	$ 890.00
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00		$ -
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00		$ -
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00		$ -
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00		$ -
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00	1	$ 5,800.00
	2,000l Cylinder	Custom Cylinder	$ 12,000.00		$ -
	3,000l Cylinder	Custom Cylinder	$ 20,000.00		$ -
	5,000l Cylinder	Custom Cylinder	$ 30,000.00		$ -
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30		$ -
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10	60	$ 2,586.00
	25mm Copper	25mm dia, per meter rate	$ 46.30		$ -
	32mm Copper	32mm dia, per meter rate	$ 67.00	10	$ 670.00
	40mm Copper	40mm dia, per meter rate	$ 79.00		$ -
	50mm Copper	50mm dia, per meter rate	$ 102.00		$ -
	15mm Insulation	13mm flexible closed cell	$ 16.30		$ -
	20mm Insulation	13mm flexible closed cell	$ 19.90	60	$ 1,194.00
	25mm Insulation	13mm flexible closed cell	$ 21.50		$ -
	32mm Insulation	13mm flexible closed cell	$ 22.20	10	$ 222.00
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00		$ -
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70		$ -
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00	1	$ 500.00
		Medium System	$ 5,000.00		$ -
		Large System	$ 12,000.00		$ -
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$28,382.00**

Solar Hot Water System Price Schedule

System: 2000l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	16	$ 32,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00		$ -
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00	1	$ 890.00
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00		$ -
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00		$ -
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00		$ -
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00		$ -
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00		$ -
	2,000l Cylinder	Custom Cylinder	$ 12,000.00	1	$ 12,000.00
	3,000l Cylinder	Custom Cylinder	$ 20,000.00		$ -
	5,000l Cylinder	Custom Cylinder	$ 30,000.00		$ -
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30		$ -
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10		$ -
	25mm Copper	25mm dia, per meter rate	$ 46.30	100	$ 4,630.00
	32mm Copper	32mm dia, per meter rate	$ 67.00		$ -
	40mm Copper	40mm dia, per meter rate	$ 79.00	10	$ 790.00
	50mm Copper	50mm dia, per meter rate	$ 102.00		$ -
	15mm Insulation	13mm flexible closed cell	$ 16.30		$ -
	20mm Insulation	13mm flexible closed cell	$ 19.90		$ -
	25mm Insulation	13mm flexible closed cell	$ 21.50	100	$ 2,150.00
	32mm Insulation	13mm flexible closed cell	$ 22.20		$ -
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00	10	$ 320.00
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70		$ -
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00		$ -
		Medium System	$ 5,000.00	1	$ 5,000.00
		Large System	$ 12,000.00		$ -
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$58,300.00**

Solar Hot Water System Price Schedule

System: 5000l System

Indicative prices based on Rawlinsons Detailed Scheduled Rates or known prices

Category	Name	Description	Unit Price	Number	Total
PANELS	Consol 30 Tube Panel	4.8m² 30 tube panel complete with manifold and frame	$ 2,000.00	40	$ 80,000.00
PUMP	Circulation Pump	Small pump < 0.2l/s	$ 495.00		$ -
	Circulation Pump	Medium pump 0.2l/s < x < 0.5l/s	$ 890.00		$ -
	Circulation Pump	Large pump > 0.5l/s	$ 1,200.00	1	$ 1,200.00
CYLINDER	300l Cylinder	Rheem 300L - 580Ø x 1825h	$ 2,000.00		$ -
	500l Cylinder	Greenglo 500D - 755Ø x 1860h	$ 3,500.00		$ -
	800l Cylinder	Greenglo 800D - 1060Ø x 1750h	$ 5,200.00		$ -
	1,000l Cylinder	Greenglo 1000D - 1060Ø x 2090	$ 5,800.00		$ -
	2,000l Cylinder	Custom Cylinder	$ 12,000.00		$ -
	3,000l Cylinder	Custom Cylinder	$ 20,000.00		$ -
	5,000l Cylinder	Custom Cylinder	$ 30,000.00	1	$ 30,000.00
VALVES	Cylinder Valve Set	Apex hot water combo valve	$ 300.00	1	$ 300.00
	Pump Valve Set	Isolating and isolating reulation valve	$ 120.00	1	$ 120.00
	Isolating Valves	15mm Brass Valve	$ 20.00		$ -
	Isolating Valves	20mm Brass Body Valve	$ 25.00		$ -
PIPEWORK	15mm Copper	15mm dia, per meter rate - allows 3 fitting per 5m	$ 32.30		$ -
	20mm Copper	20mm dia, per meter rate - allows 3 fittings per 5m	$ 43.10		$ -
	25mm Copper	25mm dia, per meter rate	$ 46.30		$ -
	32mm Copper	32mm dia, per meter rate	$ 67.00	220	$ 14,740.00
	40mm Copper	40mm dia, per meter rate	$ 79.00		$ -
	50mm Copper	50mm dia, per meter rate	$ 102.00	10	$ 1,020.00
	15mm Insulation	13mm flexible closed cell	$ 16.30		$ -
	20mm Insulation	13mm flexible closed cell	$ 19.90		$ -
	25mm Insulation	13mm flexible closed cell	$ 21.50		$ -
	32mm Insulation	13mm flexible closed cell	$ 22.20	220	$ 4,884.00
	40mm Insulation	25mm aluminium foil covered fibreglass	$ 32.00		$ -
	50mm Insulation	38mm aluminium foil covered fibreglass	$ 40.70	10	$ 407.00
ELECTRICAL	Solar Controls and Wiring	Small System	$ 500.00		$ -
		Medium System	$ 5,000.00		$ -
		Large System	$ 12,000.00	1	$ 12,000.00
MISC	Additional Monkey Toe Frame	Frame per panel	$ 500.00		$ -
	Relief Valve	Temperature/Pressure relief valve	$ 100.00	1	$ 100.00
TOTAL					**$144,771.00**

Appendix D - TRNSYS Simulation Deck File

```
VERSION 15
Open Loop System\8 Secondary Schools\500 Students\Model A - Secondary 500 students.TPF
ASSIGN "C:\trnsys15\IISiBat3\Data\Samples\Example1\EX1.LST" 6
*** Control cards
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=1
*SIMULATION Start time
* User defined CONSTANTS
TOLERANCES 0.001 0.001
LIMITS 25 10 25
DFQ 1
WIDTH 72
LIST
MAP
SOLVER 0
*** Units
* Model "Weather Input T89c" (Type 89)
UNIT 1 TYPE 89     Weather Input T89c
*$UNIT_NAME Weather Input T89c
*$MODEL .\Utility\Weather and Other Data Readers\Standard Weather File Types\Trnsys tmy\Skip N Lines before starting\TYPE89c.tmf
*$POSITION 84 125
*$LAYER Main
PARAMETERS 2
* 1 Mode
-1
* 2 Logical unit
10
*** External files
ASSIGN C:\trnsys15\Weather\Trnsys_tmy\CHRISTCHURCH.NZ.DAT 10
*|? Which file contains the TRNSYS TMY weather information? |1000
*------------------------------------------------------------------------------
* Model "Radiation T16g" (Type 16)
*
UNIT 2 TYPE 16     Radiation T16g
*$UNIT_NAME Radiation T16g
*$MODEL .\Physical Phenomena\Radiation Processors\Total Horiz, Direct Normal Known (Mode=4)\No Radiation Smoothing\TYPE16g.tmf
*$POSITION 263 29
*$LAYER Weather / Data Files
PARAMETERS 9
* 1 Horiz. radiation mode
4
* 2 Tracking mode
1
* 3 Tilted surface mode
3
* 4 Starting day
1
* 5 Latitude
43.4
* 6 Solar constant
4921.2
* 7 Shift in solar time
-5.5
* 8 Not used
2
* 9 Solar time?
-1
INPUTS 7
* Weather Input T89c:Direct normal radiation ->Total radiation on horizontal surface
1,3
```

```
* Weather Input T89c:Global horizontal radiation ->Direct normal beam radiation on horizontal
1,4
* Weather Input T89c:Time of last read ->Time of last data read
1,99
* Weather Input T89c:Time of next read ->Time of next data read
1,100
* [unconnected] Ground reflectance
0,0
* [unconnected] Slope of surface
0,0
* [unconnected] Azimuth of surface
0,0
*** INITIAL INPUT VALUES
0.0 0 0.0 1.0 0.2 0.0
0.0
*------------------------------------------------------------------------------

* Model "Collector T1b" (Type 1)
*
UNIT 3 TYPE 1    Collector T1b
*$UNIT_NAME Collector T1b
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence Angle Modifiers\TYPE1b.tmf
*$POSITION 153 445
*$LAYER Main
PARAMETERS 11
* 1 Number in series
1
* 2 Collector area
100
* 3 Fluid specific heat
4.190
* 4 Efficiency mode
1
* 5 Tested flow rate
145
* 6 Intercept efficiency
0.827
* 7 Efficiency slope
11.08872
* 8 Efficiency curvature
0.096156
* 9 Optical mode 2
2
* 10 1st-order IAM
0.06
* 11 2nd-order IAM
0.0
INPUTS 9
* Pipe to collector T31:Outlet temperature ->Inlet temperature
7,1
* Pipe to collector T31:Outlet flow rate ->Inlet flowrate
7,2
* Weather Input T89c:Dry bulb temperature ->Ambient temperature
1,5
* Radiation T16g:Total radiation on surface 1 ->Incident radiation
2,7
* Radiation T16g:Total horizontal radiation ->Total horizontal radiation
2,4
* Radiation T16g:Horizontal diffuse radiation ->Horizontal diffuse radiation
2,6
* [unconnected] Ground reflectance
0,0
* Radiation T16g:Incidence angle for surface 1 ->Incidence angle
2,10
* Radiation T16g:Slope of surface 1 ->Collector slope
2,11
*** INITIAL INPUT VALUES
20.0 100.0 10.0 0. 0.0 0.0
```

```
0.2 45.0 45
*------------------------------------------------------------------------------
* Model "Solar Controller T2a" (Type 2)
*
UNIT 4 TYPE 2    Solar Controller T2a
*$UNIT_NAME Solar Controller T2a
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\New Control
Strategy\TYPE2a.tmf
*$POSITION 266 189
*$LAYER Controls
PARAMETERS 3
* 1 New control mode
0
* 2 High limit cut-out
99
* 3 High limit reset
99
INPUTS 6
* Collector T1b:Outlet temperature ->Upper input temperature Th
3,1
* Preheat Tank T60c:Tank temperature - bottom ->Lower input temperature Tl
10,28
* Preheat Tank T60c:Tank temperature - top ->Monitoring temperature Tin
10,27
* Solar Controller T2a:Output control function ->Input control function
4,1
* [unconnected] Upper dead band dT
0,0
* [unconnected] Lower dead band dT
0,0
*** INITIAL INPUT VALUES
20.0 10.0 20.0 0 10.0 2.0
*------------------------------------------------------------------------------
* Model "LOAD T14b" (Type 14)
*
UNIT 5 TYPE 14    LOAD T14b
*$UNIT_NAME LOAD T14b
*$MODEL .\Utility\Forcing Functions\Water Draw\TYPE14b.tmf
*$POSITION 313 577
*$LAYER Main
PARAMETERS 96
* 1 Initial value of time
0
* 2 Initial value of function
0
* 3 Time at point-1
1
* 4 Water draw at point -1
0
* 5 Time at point-2
1
* 6 Water draw at point -2
32
* 7 Time at point-3
2
* 8 Water draw at point -3
32
* 9 Time at point-4
2
* 10 Water draw at point -4
48
* 11 Time at point-5
3
* 12 Water draw at point -5
48
* 13 Time at point-6
3
* 14 Water draw at point -6
32
```

* 15 Time at point-7
4
* 16 Water draw at point -7
32
* 17 Time at point-8
4
* 18 Water draw at point -8
32
* 19 Time at point-9
5
* 20 Water draw at point -9
32
* 21 Time at point-10
5
* 22 Water draw at point -10
16
* 23 Time at point-11
6
* 24 Water draw at point -11
16
* 25 Time at point-12
6
* 26 Water draw at point -12
16
* 27 Time at point-13
7
* 28 Water draw at point -13
16
* 29 Time at point-14
7
* 30 Water draw at point -14
16
* 31 Time at point-15
8
* 32 Water draw at point -15
16
* 33 Time at point-16
8
* 34 Water draw at point -16
124
* 35 Time at point-17
9
* 36 Water draw at point -17
124
* 37 Time at point-18
9
* 38 Water draw at point -18
216
* 39 Time at point-19
10
* 40 Water draw at point -19
216
* 41 Time at point-20
10
* 42 Water draw at point -20
248
* 43 Time at point-21
11
* 44 Water draw at point -21
248
* 45 Time at point-22
11
* 46 Water draw at point -22
324
* 47 Time at point-23
12
* 48 Water draw at point -23
324
* 49 Time at point-24

12
* 50 Water draw at point -24
372
* 51 Time at point-25
13
* 52 Water draw at point -25
372
* 53 Time at point-26
13
* 54 Water draw at point -26
416
* 55 Time at point-27
14
* 56 Water draw at point -27
416
* 57 Time at point-28
14
* 58 Water draw at point -28
448
* 59 Time at point-29
15
* 60 Water draw at point -29
448
* 61 Time at point-30
15
* 62 Water draw at point -30
232
* 63 Time at point-31
16
* 64 Water draw at point -31
232
* 65 Time at point-32
16
* 66 Water draw at point -32
248
* 67 Time at point-33
17
* 68 Water draw at point -33
248
* 69 Time at point-34
17
* 70 Water draw at point -34
292
* 71 Time at point-35
18
* 72 Water draw at point -35
292
* 73 Time at point-36
18
* 74 Water draw at point -36
372
* 75 Time at point-37
19
* 76 Water draw at point -37
372
* 77 Time at point-38
19
* 78 Water draw at point -38
140
* 79 Time at point-39
20
* 80 Water draw at point -39
140
* 81 Time at point-40
20
* 82 Water draw at point -40
124
* 83 Time at point-41
21

```
* 84 Water draw at point -41
124
* 85 Time at point-42
21
* 86 Water draw at point -42
108
* 87 Time at point-43
22
* 88 Water draw at point -43
108
* 89 Time at point-44
22
* 90 Water draw at point -44
92
* 91 Time at point-45
23
* 92 Water draw at point -45
92
* 93 Time at point-46
23
* 94 Water draw at point -46
60
* 95 Time at point-47
24
* 96 Water draw at point -47
60
*------------------------------------------------------------------------------
* Model "Pump T3b" (Type 3)
*
UNIT 6 TYPE 3    Pump T3b
*$UNIT_NAME Pump T3b
*$MODEL .\Hydronics\Pump\TYPE3b.tmf
*$POSITION 634 200
*$LAYER Water Loop
PARAMETERS 5
* 1 Maximum flow rate
4000
* 2 Fluid specific heat
4.190
* 3 Maximum power
702
* 4 Conversion coefficient
0.10
* 5 Power coefficient
0.5
INPUTS 3
* Preheat Tank T60c:Temperature of outlet flow 2 ->Inlet fluid temperature
10,6
* [unconnected] Inlet mass flow rate
0,0
* Solar Controller T2a:Output control function ->Control signal
4,1
*** INITIAL INPUT VALUES
20.0 720 0
*------------------------------------------------------------------------------
* Model "Pipe to collector T31" (Type 31)
*
UNIT 7 TYPE 31    Pipe to collector T31
*$UNIT_NAME Pipe to collector T31
*$MODEL .\Hydronics\Pipe_Duct\TYPE31.tmf
*$POSITION 160 306
*$LAYER Water Loop
PARAMETERS 6
* 1 Inside diameter
0.013
* 2 Pipe length
10
* 3 Loss coefficient
18.936
```

```
* 4 Fluid density
1000.0
* 5 Fluid specific heat
4.190
* 6 Initial fluid temperature
10.0
INPUTS 3
* Pump T3b:Outlet fluid temperature ->Inlet temperature
6,1
* Pump T3b:Outlet flow rate ->Inlet flow rate
6,2
* [unconnected] Environment temperature
0,0
*** INITIAL INPUT VALUES
10.0 100.0 20
*------------------------------------------------------------------------------
* Model "Pipe from collector T31" (Type 31)
*
UNIT 8 TYPE 31    Pipe from collector T31
*$UNIT_NAME Pipe from collector T31
*$MODEL .\Hydronics\Pipe_Duct\TYPE31.tmf
*$POSITION 371 338
*$LAYER Water Loop
PARAMETERS 6
* 1 Inside diameter
.013
* 2 Pipe length
10
* 3 Loss coefficient
18.936
* 4 Fluid density
1000.0
* 5 Fluid specific heat
4.190
* 6 Initial fluid temperature
10.0
INPUTS 3
* Collector T1b:Outlet temperature ->Inlet temperature
3,1
* Collector T1b:Outlet flowrate ->Inlet flow rate
3,2
* [unconnected] Environment temperature
0,0
*** INITIAL INPUT VALUES
10.0 100.0 20
*------------------------------------------------------------------------------
* Model "WH Temp T14e" (Type 14)
*
UNIT 9 TYPE 14    WH Temp T14e
*$UNIT_NAME WH Temp T14e
*$MODEL .\Utility\Forcing Functions\Temperature\TYPE14e.tmf
*$POSITION 127 530
*$LAYER Main
PARAMETERS 48
* 1 Initial value of time
0
* 2 Initial temperature
16
* 3 Time at point-1
744
* 4 Temperature at point -1
16
* 5 Time at point-2
744
* 6 Temperature at point -2
16
* 7 Time at point-3
1416
* 8 Temperature at point -3
```

16
* 9 Time at point-4
1416
* 10 Temperature at point -4
15
* 11 Time at point-5
2160
* 12 Temperature at point -5
15
* 13 Time at point-6
2160
* 14 Temperature at point -6
11
* 15 Time at point-7
2880
* 16 Temperature at point -7
11
* 17 Time at point-8
2880
* 18 Temperature at point -8
9
* 19 Time at point-9
3624
* 20 Temperature at point -9
9
* 21 Time at point-10
3624
* 22 Temperature at point -10
6
* 23 Time at point-11
4344
* 24 Temperature at point -11
6
* 25 Time at point-12
4344
* 26 Temperature at point -12
5
* 27 Time at point-13
5088
* 28 Temperature at point -13
5
* 29 Time at point-14
5088
* 30 Temperature at point -14
6
* 31 Time at point-15
5832
* 32 Temperature at point -15
6
* 33 Time at point-16
5832
* 34 Temperature at point -16
8
* 35 Time at point-17
6552
* 36 Temperature at point -17
8
* 37 Time at point-18
6552
* 38 Temperature at point -18
11
* 39 Time at point-19
7296
* 40 Temperature at point -19
11
* 41 Time at point-20
7296
* 42 Temperature at point -20
13

```
* 43 Time at point-21
8016
* 44 Temperature at point -21
13
* 45 Time at point-22
8016
* 46 Temperature at point -22
15
* 47 Time at point-23
8760
* 48 Temperature at point -23
15
*------------------------------------------------------------------------------
* Model "Preheat Tank T60c" (Type 60)
*
UNIT 10 TYPE 60	 Preheat Tank T60c
*$UNIT_NAME Preheat Tank T60c
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Vertical Cylinder\Uniform Losses and Node Heights\2
Inlets, 2 Outlets\TYPE60cNoHeat.tmf
*$POSITION 518 466
*$LAYER Main
PARAMETERS 32
* 1 User-specified inlet positions
2
* 2 Tank volume
5
* 3 Tank height
2.09
* 4 Tank perimeter
-1
* 5 Height of flow inlet 1
0.1
* 6 Height of flow outlet 1
2
* 7 Height of flow inlet 2
0.1
* 8 Height of flow outlet 2
0.4
* 9 Fluid specific heat
4.190
* 10 Fluid density
1000.0
* 11 Tank loss coefficient
7.64
* 12 Fluid thermal conductivity
2.1
* 13 Destratification conductivity
0.0
* 14 Boiling temperature
100.0
* 15 Auxiliary heater mode
1
* 16 Height of 1st aux. heater
1.0
* 17 Height of 1st thermostat
1.25
* 18 Set point temperature for element 1
55.0
* 19 Deadband for heating element 1
5.0
* 20 Maximum heating rate of element 1
0
* 21 Height of heating element 2
1
* 22 Height of thermostat 2
1
* 23 Set point temperature for element 2
55.0
* 24 Deadband for heating element 2
```

5.0
* 25 Maximum heating rate of element 2
0
* 26 Overall loss coefficient for gas flue
0.0
* 27 Flue temperature
20.0
* 28 Fraction of critical timestep
6
* 29 Gas heater?
0
* 30 Number of internal heat exchangers
0
* 31 Equal sized nodes
0
* 32 Uniform tank losses
0
INPUTS 9
* LOAD T14b:Instantaneous water draw ->Flow rate at inlet 1
5,2
* [unconnected] Flow rate at outlet 1
0,0
* Pipe from collector T31:Outlet flow rate ->Flow rate at inlet 2
8,2
* Pipe from collector T31:Outlet flow rate ->Flow rate at outlet 2
8,2
* WH Temp T14e:Instantaneous temperature ->Temperature at inlet 1
9,2
* Pipe from collector T31:Outlet temperature ->Temperature at inlet 2
8,1
* [unconnected] Environment temperature
0,0
* [unconnected] Control signal for element 1
0,0
* [unconnected] Control signal for element 2
0,0
*** INITIAL INPUT VALUES
0.0 -2 0.0 0 20.0 20.0
20 1.0 1.0
DERIVATIVES 18
* 1 Initial temperature of node-1
0
* 2 Initial temperature of node-2
0
* 3 Initial temperature of node-3
0
* 4 Initial temperature of node-4
0
* 5 Initial temperature of node-5
0
* 6 Initial temperature of node-6
0
* 7 Initial temperature of node-7
0
* 8 Initial temperature of node-8
0
* 9 Initial temperature of node-9
0
* 10 Initial temperature of node-10
0
* 11 Initial temperature of node-11
0
* 12 Initial temperature of node-12
0
* 13 Initial temperature of node-13
0
* 14 Initial temperature of node-14
0
* 15 Initial temperature of node-15

```
0
* 16 Initial temperature of node-16
0
* 17 Initial temperature of node-17
0
* 18 Initial temperature of node-18
0
*------------------------------------------------------------------------------
* Model "Temp1 T65" (Type 65)
*
UNIT 11 TYPE 65    Temp1 T65
*$UNIT_NAME Temp1 T65
*$MODEL .\Output\Online Plotter\TYPE65.tmf
*$POSITION 882 413
*$LAYER Main
PARAMETERS 10
* 1 # of left-axis variables
6
* 2 # of right-axis variables
1
* 3 Left axis minimum
-20
* 4 Left axis maximum
100.0
* 5 Right axis minimum
-20
* 6 Right axis maximum
100.0
* 7 Number of plots per simulation
12
* 8 X-axis gridpoints
7
* 9 Shut off Online w/o removing
0
* 10 Logical Unit for ouput file
-1
INPUTS 7
* WH Temp T14e:Instantaneous temperature ->Left axis variable-1
9,2
* Preheat Tank T60c:Temperature of outlet flow 2 ->Left axis variable-2
10,6
* Collector T1b:Outlet temperature ->Left axis variable-3
3,1
* Pipe from collector T31:Outlet temperature ->Left axis variable-4
8,1
* Preheat Tank T60c:Temperature of outlet flow 1 ->Left axis variable-5
10,5
* Auxiliary Heat T6:Outlet fluid temperature ->Left axis variable-6
14,1
* Weather Input T89c:Dry bulb temperature ->Right axis variable
1,5
*** INITIAL INPUT VALUES
WH Out2 Coll In2 Out1 HW
OA
LABELS  5
C C
Temperatures
Temperature
Temperature Result
*------------------------------------------------------------------------------
* Model "Flow1 T65" (Type 65)
*
UNIT 12 TYPE 65    Flow1 T65
*$UNIT_NAME Flow1 T65
*$MODEL .\Output\Online Plotter\TYPE65.tmf
*$POSITION 912 584
*$LAYER Main
PARAMETERS 10
* 1 # of left-axis variables
```

```
1
* 2 # of right-axis variables
1
* 3 Left axis minimum
0
* 4 Left axis maximum
500
* 5 Right axis minimum
0
* 6 Right axis maximum
500
* 7 Number of plots per simulation
12
* 8 X-axis gridpoints
7
* 9 Shut off Online w/o removing
0
* 10 Logical Unit for ouput file
-1
INPUTS 2
* LOAD T14b:Instantaneous water draw ->Left axis variable
5,2
* Pump T3b:Outlet flow rate ->Right axis variable
6,2
*** INITIAL INPUT VALUES
HW SOL
LABELS  5
kg/hr  kg/hr
Flow rate
Flow Rate
Flow Rate Results
*------------------------------------------------------------------------------
* EQUATIONS "Equation"
*
EQUATIONS 1
QENV = [7,3]+[8,3]+[10,7]
*$UNIT_NAME Equation
*$LAYER Main
*$POSITION 599 100
*------------------------------------------------------------------------------
* Model "Auxiliary Heat T6" (Type 6)
*
UNIT 14 TYPE 6    Auxiliary Heat T6
*$UNIT_NAME Auxiliary Heat T6
*$MODEL .\Hvac\Auxiliary Heaters\TYPE6.tmf
*$POSITION 675 296
*$LAYER Water Loop
*$#
*$#
*$#
PARAMETERS 4
* 1 Maximum heating rate
9999999999
* 2 Specific heat of fluid
4.19
* 3 Overall loss coefficient for heater during operation
0.0
* 4 Efficiency of auxiliary heater
1.0
INPUTS 5
* Preheat Tank T60c:Temperature of outlet flow 1 ->Inlet fluid temperature
10,5
* Preheat Tank T60c:Flowrate at outlet 1 ->Fluid mass flow rate
10,2
* [unconnected] Control Function
0,0
* [unconnected] Set point temperature
0,0
* [unconnected] Temperature of surroundings
```

```
0,0
*** INITIAL INPUT VALUES
20.0 0 1 60.0 20.0
*------------------------------------------------------------------------------
* Model "Printer T25b" (Type 25)
*
UNIT 15 TYPE 25    Printer T25b
*$UNIT_NAME Printer T25b
*$MODEL .\Output\Printer\Print User-Supplied Units to File\TYPE25b.tmf
*$POSITION 895 50
*$LAYER Outputs
PARAMETERS 6
* 1 Printing interval
-1
* 2 Start time
0
* 3 Stop time
8760
* 4 Logical unit
17
* 5 User supplied units
1
* 6 Output format ""normal"" or ""SPREADSHEET""
0
INPUTS 5
* Integrator T24:Result of integration-1 ->Input to be printed-1
16,1
* Integrator T24:Result of integration-2 ->Input to be printed-2
16,2
* Integrator T24:Result of integration-3 ->Input to be printed-3
16,3
* Integrator T24:Result of integration-4 ->Input to be printed-4
16,4
* Integrator T24:Result of integration-5 ->Input to be printed-5
16,5
*** INITIAL INPUT VALUES
TOTSOL QSOL QENV QADD QAUX
kJ/m2 kJ kJ kJ kJ
*** External files
ASSIGN C:\trnsys15\Weather\Tmy2\BEGIN.OUT 17
*|? Which file should contain the printed results? |1000
*------------------------------------------------------------------------------
* Model "Integrator T24" (Type 24)
UNIT 16 TYPE 24    Integrator T24
*$UNIT_NAME Integrator T24
*$MODEL .\Utility\Integrators\Quantity Integrator\TYPE24.tmf
*$POSITION 792 50
*$LAYER Main
*$#
*$#
PARAMETERS 1
* 1 Reset time
8760.0
INPUTS 5
* Radiation T16g:Total radiation on surface 1 ->Input to be integrated-1
2,7
* Collector T1b:Useful energy gain ->Input to be integrated-2
3,3
* Equation:QENV ->Input to be integrated-3
QENV
* Pump T3b:Power consumption ->Input to be integrated-4
6,3
* Auxiliary Heat T6:Rate of energy delivery to fluid stream ->Input to be integrated-5
14,5
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------
END
```